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ON
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IN

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WITH

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AND

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With the SUPPLEMENT.

By JAMES FERGUSON, F. R. S.

THE SECOND EDITION.

Philosophia mater omnium bonarum artium est. Cicero. I. Tusc.

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SIR,

As heaven has inspired your Royal Highness with such love of ingenious and useful arts, that you not only study their theory, but have often condescended to honour the professors of mechanical and experimental philosophy with your presence

TO HIS

ROYAL HIGHNESS

Prince EDWARD.

SIR,

AS heaven has inſpired your ROYAL HIGHNESS with ſuch love of ingenious and uſeful arts, that you not only ſtudy their theory, but have often condeſcended to honour the profeſſors of mechanical and experimental philoſophy with your preſence

ſence and particular favour; I am thereby encouraged to lay myſelf and the following work at your ROYAL HIGHNESS's feet; and at the ſame time beg leave to expreſs that veneration with which I am,

SIR,

Your ROYAL HIGHNESS's

Moſt obliged,

And moſt obedient,

Humble Servant,

James Ferguſon.

THE

PREFACE.

EVER *since the days of the* LORD CHANCELLOR BACON, *natural philosophy hath been more and more cultivated in England.* THAT *great genius first set out with taking a general survey of all the natural sciences, dividing them into distinct branches, which he enumerated with great exactness. He enquired scrupulously into the degree of knowledge already attained to in each, and drew up a list of what still remained to be discovered: this was the scope of his first undertaking. Afterward he carried his views*

much farther, and shewed the necessity of an experimental philosophy, a thing never before thought of. As he was a professed enemy to systems, he considered philosophy no otherwise than as that part of knowledge which contributes to make men better and happier: he seems to limit it to the knowledge of things useful, recommending above all the study of nature, and shewing that no progress can be made therein, but by collecting facts, and comparing experiments, of which he points out a great number proper to be made.

But notwithstanding the true path to science was thus exactly marked out, the old notions of the schools so strongly possessed people's minds at that time, as not to be eradicated by any new opinions, how rationally soever advanced, until the illustrious Mr. BOYLE, *the first who pursued* LORD BACON's *plan, began to put experiments in practice with an assiduity equal to his great talents. Next, the* ROYAL SOCIETY *being established, the true philosophy began to be the reigning taste of the age, and continues so to this day.*

The immortal SIR ISAAC NEWTON *insisted even in his early years, that it was high time to banish vague conjectures and hypotheses from natural philosophy, and to bring that science under an entire subjection to experiments and geometry. He frequently called it* the experimental philosophy, *so as to express significantly the difference between it and the numberless systems which had arisen merely out of the conceits of inventive brains: the one subsisting no longer than the spirit of novelty lasts; the other never failing whilst the nature of things remain unchanged.*

The method of teaching and laying the foundation of physics, by public courses of experiments, was first undertaken in this kingdom, I believe, by Dr. JOHN KEILL, *and since improved and enlarged by Mr.* HAUKSBEE, *Dr.* DESAGULIERS, *Mr.* WHISTON, *Mr.* COTES, *Mr.* WHITESIDE, *Dr.* BRADLEY, *our late Regius and Savilian professor of Astronomy, and the Reverend Dr.* BLISS *his successor.*——

Nor

Nor has the same been neglected by Dr. JAMES, *and* Dr. DAVID GREGORY, *Sir* ROBERT STEWART, *and after him* Mr. MACLAURIN.——Dr. HELSHAM *in Ireland, Messieurs* s'GRAVESANDE *and* MUSCHENBROEK, *and the Abbe* NOLLET *in France, have also acquired just applause thereby.*

The substance of my own attempt in this way of instrumental instruction, the following sheets (exclusive of the astronomical part) will shew: the satisfaction they have generally given, read as lectures to different audiences, affords me some hope that they may be favourably received in the same form by the public.

I ought to observe, that though the five last lectures cannot be properly said to concern experimental philosophy, I considered, however, that they were not of so different a class, but that they might, without much impropriety, be subjoined to the preceding ones.

*My apparatus (part of which is described here, and the rest in a * former work) is rather simple than magnificent; which is owing to a particular point I had in view at first setting out, namely, to avoid all superfluity, and to render every thing as plain and intelligible as I thought the subject would admit of.*

* Astronomy explained upon Sir Isaac Newton's principles, and made easy to those who have not studied mathematics.

THE

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In page 59, *the second paragraph of* LECTURE V should be as follows,

A fluid is a body that yields to the least pressure, or difference of pressures. Its particles are so small, that they cannot be discerned by the best microscopes; and they must be round and smooth, because they are so easily moved among one another. Air is a very compressible fluid, but water has been generally thought to be an incompressible one, till of late, that Mr. *Canton* has shewn, by very fair experiments, that it is compressible in a small degree.

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LEC-

LECTURES
ON
SELECT SUBJECTS.

LECT. I.

Of matter and its properties.

AS the design of the first part of this course is to explain and demonstrate those laws by which the material universe is governed, regulated, and continued; and by which the various appearances in nature are accounted for; it is requisite to begin with explaining the properties of matter.

By the word *matter* is here meant every thing that has length, breadth, and thickness, and resists the touch. Matter, what.

The inherent properties of matter are solidity, inactivity, mobility, and divisibility. Its properties.

The *solidity* of matter arises from its having length, breadth, thickness; and hence it is that all bodies are comprehended under some shape or other, and that every particular body hinders all others from occupying the same part of space which it possesseth. Thus, if a piece of wood or metal be squeezed ever so hard between two plates, they cannot be brought into contact. And even water or air has this property; for if a small quantity of it be fixed between any other Solidity.

 bodies,

bodies, they cannot be brought to touch one another.

Inactivity. A ſecond property of matter is *inactivity*, or *paſſiveneſs*; by which it always endeavours to continue in the ſtate that it is in, whether of reſt or motion. And therefore, if one body contains twice or thrice as much matter as another body does, it will have twice or thrice as much inactivity; that is, it will require twice or thrice as much force to give it an equal degree of motion, or to ſtop it after it hath been put into ſuch a motion.

That matter can never put itſelf into motion is allowed by all men. For they ſee that a ſtone, lying on the plane ſurface of the earth, never removes itſelf from that place, nor does any one imagine it ever can. But moſt people are apt to believe that all matter has a propenſity to fall from a ſtate of motion into a ſtate of reſt; becauſe they ſee that if a ſtone or a cannon-ball be put into ever ſo violent a motion, it ſoon ſtops; not conſidering that this ſtoppage is cauſed, 1. by the gravity or weight of the body, which ſinks it to the ground in ſpite of the impulſe; and, 2. by the reſiſtance of the air through which it moves, and by which its velocity is retarded every moment till it falls.

A bowl moves but a ſhort way upon a bowling-green; becauſe the roughneſs and unevenneſs of the graſſy ſurface ſoon creates friction enough to ſtop it. But if the green were perfectly level, and covered with poliſhed glaſs, and the bowl were perfectly hard, round, and ſmooth, it would go a great way further; as it would have nothing but the air to reſiſt it: if then the air were taken away, the bowl would go on without any friction, and conſequently without any

any diminution of the velocity it had at ſetting out: and therefore, if the green were extended quite around the earth, the bowl would go on, round and round the earth, for ever.

If the bowl were carried ſeveral miles above the earth, and there projected in a horizontal direction, with ſuch a velocity as would make it move more than a ſemidiameter of the earth, in the time it would take to fall to the earth by gravity; in that caſe, and if there were no reſiſting medium in the way, the bowl would not fall to the earth at all; but would continue to circulate round it, keeping always in the ſame tract, and returning to the ſame point from which it was projected, with the ſame velocity as at firſt. In this manner the moon moves round the earth, although ſhe be as unactive and dead as any ſtone upon it.

Mobility. The third property of matter is *mobility*; for we find that all matter is capable of being moved, if a ſufficient degree of force be applied to overcome its inactivity or reſiſtance.

Diviſibility. The fourth property of matter is *diviſibility*, of which there can be no end. For, ſince matter can never be annihilated by cutting or breaking, we can never imagine it to be cut into ſuch ſmall particles, but that if one of them be laid on a table, the uppermoſt ſide of it will be further from the table than the undermoſt ſide. Moreover, it would be abſurd to ſay that the greateſt mountain on earth has more halves, quarters, or tenth parts, than the ſmalleſt particle of matter has.

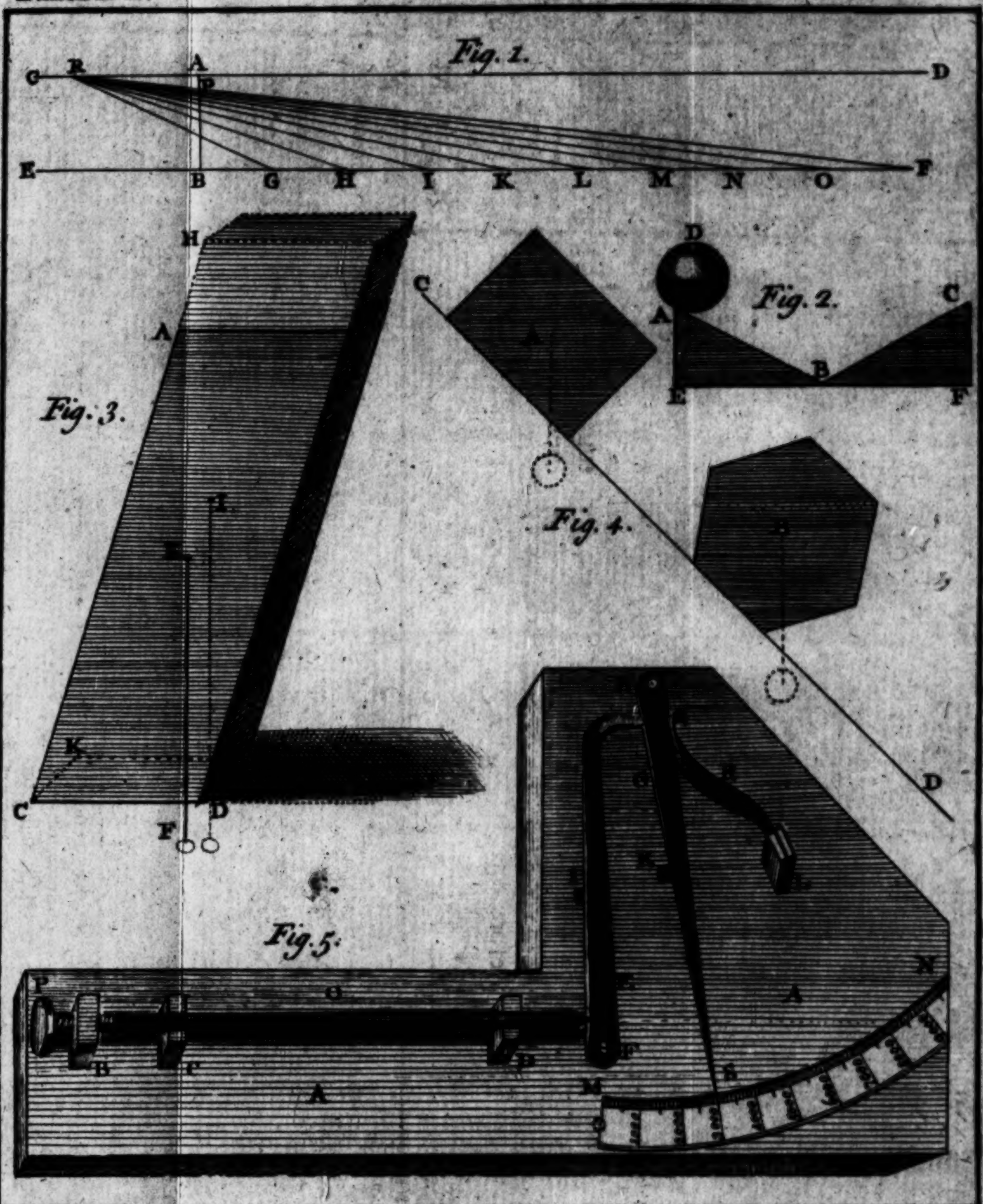
We have many ſurpriſing inſtances of the ſmallneſs to which matter can be divided by art: of which the two following are very remarkable.

1. If a pound of silver be fused with a single grain of gold, the gold will be equally diffused through the whole silver; so that taking one grain from any part of the mass (in which there can be no more than the 5760th part of a grain of gold) and dissolving it in *aqua fortis*, the gold will fall to the bottom.

2. The gold-beaters can extend a grain of gold into a leaf containing 50 square inches; and this leaf may be divided into 500000 parts. For an inch in length can be divided into 100 parts, every one of which will be visible to the bare eye: consequently a square inch can be divided into 10000 parts, and 50 square inches into 500000. And if one of these parts be viewed with a microscope that magnifies the diameter of an object only 10 times, it will magnify the area 100 times; and then the 100th part of a 500000th part of a grain (that is, the 50 millionth part) will be visible. Such leaves are commonly used in gilding; and they are so very thin, that if 124500 of them were laid upon one another, and pressed together, they would not exceed one inch in thickness.

Yet all this is nothing in comparison of the lengths that nature goes in the division of matter. For Mr. *Leewenhoek* tells us, that there are more animals in the milt of a single cod fish, than there are men upon the whole earth: and that, by comparing these animals in a microscope with grains of common sand, it appeared that one single grain is bigger than four millions of them. Now each animal must have a heart, arteries, veins, muscles, and nerves, otherwise they could neither live nor move. How inconceivably small then must the particles of their blood be, to circulate through the smallest ramifications

PLATE I.



J. Ferguson delin.

J. Mynde sc.

fications and joinings of their arteries and veins? It has been found by calculation, that a particle of their blood must be as much smaller than a globe of the tenth part of an inch in diameter, as that globe is smaller than the whole earth; and yet, if these particles be compared with the particles of light, they will be found to exceed them as much in bulk as mountains do single grains of sand. For, the force of any body striking against an obstacle is directly in proportion to its quantity of matter multiplied into its velocity: and since the velocity of the particles of light is demonstrated to be at least a million times greater than the velocity of a cannon-ball, it is plain, that if a million of these particles were as big as a single grain of sand, we durst no more open our eyes to the light, than we durst expose them to sand shot point-blank from a cannon.

Plate I. Fig. 1.

The infinite divisibility of matter proved.

That matter is infinitely divisible, in a mathematical sense, is easy to be demonstrated. For, let *AB* be the length of a particle to be divided; and let it be touched at opposite ends by the parallel lines *CD* and *EF*, which, suppose to be infinitely extended beyond *D* and *F*. Set off the equal divisions *BG*, *GH*, *HI*, &c. on the line *EF*, towards the right hand from *B*; and take a point, as at *R*, any where toward the left hand from *A*, in the line *CD*: Then, from this point, draw the right lines *RG*, *RH*, *RI*, &c. each of which will cut off a part from the particle *AB*. But after any finite number of such lines are drawn, there will still remain a part, as *AP*, at the top of the particle, which can never be cut off: because the lines *DR* and *EF* being parallel, no line can ever be drawn from the point *R* to any point of the line *EF* that will

coincide with the line *RD*. Therefore the particle *AB* contains more than any finite number of parts.

Attraction. A fifth property of matter is ***attraction***, which seems rather to be infused than inherent. Of this there are four kinds, viz. ***cohesion***, ***gravitation***, ***magnetism***, and ***electricity***.

Cohesion. The ***attraction of cohesion*** is that by which the small parts of matter are made to stick and cohere together. Of this we have several instances, some of which follow.

1. If a small glass tube, open at both ends, be dipt in water, the water will rise up in the tube to a considerable height above its level in the bason: which must be owing to the attraction of a ring of particles of the glass all around in the tube, immediately above those to which the water at any instant rises. And when it has risen so high, that the weight of the column balances the attraction of the tube, it rises no higher. This can be no ways owing to the pressure of the air upon the water in the bason; for, as the tube is open at top, it is full of air above the water, which will press as much upon the water in the tube as the neighbouring air does upon any column of an equal diameter in the bason. Besides, if the same experiment be made in an exhausted receiver of the air-pump, there will be found no difference.

2. A piece of loaf-sugar will draw up a fluid, and a spunge will suck in water: and on the same principle sap ascends in trees.

3. If two drops of quicksilver be placed near each other, they will run together and become one large drop.

4. If two pieces of lead be scraped clean, and pressed together with a twist, they will attract each

each other so strongly, as to require a force much greater than their own weight to separate them. And this cannot be owing to the pressure of the air, for the same thing will hold in an exhausted receiver.

5. If two polished plates of marble or brass be put together, with a little oil between them to fill up the pores in their surfaces, and prevent the lodgment of any air; they will cohere so strongly, even if suspended in an exhausted receiver, that the weight of the lower plate will not be able to separate it from the upper one. In putting these plates together, the one should be rubbed upon the other, as a joiner does two pieces of wood when he glues them.

6. If two pieces of cork, equal in weight, be put near each other in a bason of water, they will move equally fast toward each other with an accelerated motion, until they meet: and then, if either of them be moved, it will draw the other after it. If two corks of unequal weights be placed near each other, they will approach with accelerated velocities inversely proportionate to their weights: that is, the lighter cork will move as much faster than the heavier, as the heavier exceeds the lighter in weight. This shews that the attraction of each cork is in direct proportion to its weight or quantity of matter.

This kind of attraction reaches but to a very small distance; for, if two drops of quicksilver be rolled in dust, they will not run together, because the particles of dust keep them out of the sphere of each other's attraction.

Where the sphere of attraction ends, a *repulsive force* begins; thus, water repels most bodies till they are wet; and hence it is that a small Repulsion.

needle, if dry, ſwims upon water; and flies walk upon it without wetting their feet.

The repelling force of the particles of a fluid is but ſmall; and therefore, if a fluid be divided, it eaſily unites again. But if glaſs, or any other hard ſubſtance, be broke into ſmall parts, they cannot be made to ſtick together again without being firſt wetted: the repulſion being too great to admit of a re-union.

The repelling force between water and oil is ſo great, that we find it almoſt impoſſible to mix them ſo, as not to ſeparate again. If a ball of light wood be dipt in oil, and then put into water, the water will recede ſo as to form a channel of ſome depth all around the ball.

The repulſive force of the particles of air is ſo great, that they can never be brought ſo near together by condenſation as to make them ſtick or cohere. Hence it is, that when the weight of the incumbent atmoſphere is taken off from any ſmall quantity of air, that quantity will diffuſe itſelf ſo as as to occupy (in compariſon) an infinitely greater portion of ſpace than it did before.

Gravitation. *Attraction of gravitation* is that power by which diſtant bodies tend towards one another. Of this we have daily inſtances in the falling of bodies to the earth. By this power in the earth it is, that bodies, on whatever ſide, fall in lines perpendicular to its ſurface; and conſequently, on oppoſite ſides, they fall in oppoſite directions; all towards the center, where the force of gravity is as it were accumulated: and by this power it is, that bodies on the earth's ſurface are kept to it on all ſides, ſo that they cannot fall from it. And as it acts upon all bodies in proportion to their reſpective quantities of matter, without any regard to their bulks or figures,

figures, it accordingly constitutes their weight. Hence,

If two bodies which contain equal quantities of matter, were placed at ever so great a distance from one another, and then left at liberty in free space; if there were no other bodies in the universe to affect them, they would fall equally swift towards one another by the power of gravity, with velocities accelerated as they approached each other; and would meet in a point which was half way between them at first. Or, if two bodies containing unequal quantities of matter, were placed at any distance, and left in the same manner at liberty, they would fall towards one another with velocities which would be in an inverse proportion to their respective quantities of matter; and moving faster and faster in their mutual approach, would at last meet in a point as much nearer to the place from which the heavier body began to fall, than to the place from which the lighter body began to fall, as the quantity of matter in the former exceeded that in the latter.

All bodies that we know of have gravity or weight. For, that there is no such thing as positive levity, even in smoke, vapours, and fumes, is demonstrable by experiments on the air-pump; which shews, that although the smoke of a candle ascends to the top of a tall receiver, when full of air, yet, upon the air's being exhausted out of the receiver, the smoke falls down to the bottom of it. So, if a piece of wood be immersed in a jar of water, the wood will rise to the top of the water, because it has a less degree of weight than its bulk of water has; but if the jar be emptied of water, the wood falls to the bottom.

As

Gravity demonstrated to be as the quantity of matter in bodies.

As every particle of matter has its proper gravity, the effect of the whole must be in proportion to the number of the attracting particles; that is, as the quantity of matter in the whole body. This is demonstrable by experiments on pendulums; for, if they are of equal lengths, whatever their weights be, they vibrate in equal times. Now it is plain, that if one be double or triple the weight of another, it must require a double or triple power of gravity to make it move with the same celerity: just as it would require a double or triple force to project a bullet of twenty or thirty pound weight with the same degree of swiftness that a bullet of ten pounds would require. Hence it is evident, that the power or force of gravity is always proportional to the quantity of matter in bodies, whatever their bulks or figures are.

It decreases as the square of the distance increases.

Gravity also, like all other virtues or emanations which proceed or issue from a center, decreases as the distance multiplied by itself increases: that is, a body at twice the distance of another attracts with only a fourth part of the force; at thrice the distance, with a ninth part; at four times the distance, with a sixteenth part; and so on. This too is confirmed by comparing the distance which the moon falls in a minute, from a right line touching her orbit, with the distance through which heavy bodies near the earth fall in that time. And also by comparing the forces which retain Jupiter's moons in their orbits, with their respective distances from Jupiter. These forces will be explained in the next lecture.

The velocity which bodies near the earth acquire in descending freely by the force of gravity, is proportional to the times of their descent. For,

For, as the power of gravity does not conſiſt in a ſingle impulſe, but is always operating in a conſtant and uniform manner, it muſt produce equal effects in equal times; and conſequently in a double or triple time, a double or triple effect. And ſo, by acting uniformly on the body, muſt accelerate its motion proportionably to the time of its deſcent.

To be a little more particular on this ſubject, let us ſuppoſe that a body begins to move with a celerity conſtantly and gradually increaſing, in ſuch a manner, as would carry it through a mile in a minute; at the end of this ſpace it will have acquired ſuch a degree of celerity, as is ſufficient to carry it two miles the next minute, though it ſhould then receive no new impulſe from the cauſe by which its motion had been accelerated: but if the ſame accelerating cauſe continues, it will carry the body a mile farther; on which account, it will have run through four miles at the end of two minutes; and then it will have acquired ſuch a degree of celerity as is ſufficient to carry it through a double ſpace in as much more time, or eight miles in two minutes, even though the accelerating force ſhould act upon it no more. But this force ſtill continuing to operate in an uniform manner, will again, in an equal time, produce an equal effect; and ſo, by carrying it a mile further, cauſe it to move through five miles the third minute: for, the celerity already acquired, and the celerity ſtill acquiring, will have each its compleat effect. Hence we learn, that if the body ſhould move one mile the firſt minute, it would move three the ſecond, five the third, ſeven the fourth, nine the fifth, and ſo on in proportion.

And

And thus it appears, that the ſpaces deſcribed in ſucceſſive equal parts of time, by an uniformly accelerated motion, are always as the odd numbers 1, 3, 5, 7, 9, &c. and conſequently, the whole ſpaces are as the ſquares of the times, or of the laſt acquired velocities. For, the continued addition of the odd numbers yields the ſquares of all numbers from unity upwards. Thus, 1 is the firſt odd number, and the ſquare of 1 is 1; 3 is the ſecond odd number, and this added to 1 makes 4, the ſquare of 2; 5 is the third odd number, which added to 4 makes 9, the ſquare of 3; and ſo on for ever. Since, therefore, the times and velocities proceed evenly and conſtantly as 1, 2, 3, 4, &c. but the ſpaces deſcribed in each equal time are as 1, 3, 5, 7, &c. it is evident that the ſpace deſcribed

In 1 minute will be - - - $1 =$ ſquare of 1
In 2 minutes - - $1+3= 4 =$ ſquare of 2
In 3 minutes - $1+3+5= 9 =$ ſquare of 3
In 4 minutes $1+3+5+7=16 =$ ſquare of 4 &c.

N. B. The character $+$ ſignifies *more*, and $=$ *equal*.

The deſcending velocity will give a power of equal aſcent.

As heavy bodies are uniformly accelerated by the power of gravity in their deſcent, it is plain that they muſt be uniformly retarded by the ſame power in their aſcent. Therefore, the velocity which a body acquires by falling, is ſufficient to carry it up again to the ſame height from whence it fell: allowance being made for the reſiſtance of the air, or other medium in which the body is moved. Thus, the body *D* in rolling down the inclined plane *AB* will acquire ſuch a velocity by the time it arrives at

Fig. 2.

B, as

B, as will carry it up the inclined plane *BC*, almoſt to *C*; and would carry it quite up to *C*, if the body and plane were perfectly ſmooth, and the air gave no reſiſtance.—So, if a pendulum were put into motion in a ſpace quite void of air, and all other reſiſtance, and had no friction on the point of ſuſpenſion, it would move for ever: for the velocity it had acquired in falling through the deſcending part of the arc, would be ſtill ſufficient to carry it equally high in the aſcending part thereof.

The *center of gravity* is that point of a body in which the whole force of its gravity or weight is united. Therefore, whatever ſupports that point bears the weight of the whole body: and whilſt it is ſupported, the body cannot fall; becauſe all its parts are in a perfect equilibrium about that point. The center of gravity,

An imaginary line drawn from the center of gravity of any body towards the center of the earth, is called the *line of direction*. In this line all heavy bodies deſcend, if not obſtructed. and line of direction.

Since the whole weight of a body is united in its center of gravity, as that center aſcends or deſcends we muſt look upon the whole body to do ſo too. But as it is contrary to the nature of heavy bodies to aſcend of their own accord, or not to deſcend when they are permitted; we may be ſure that, unleſs the center of gravity be ſupported, the whole body will tumble or fall. Hence it is, that bodies ſtand upon their baſes when the line of direction falls within the baſe; for in this caſe the body cannot be made to fall without firſt raiſing the center of gravity higher than it was before. Thus, the inclining body *ABCD*, whoſe center of gravity is *E*, ſtands firmly on its baſe *CDIK*, becauſe the line of Fig. 3.

of direction *E F* falls within the base. But if a weight, as *ABGH*, be laid upon the top of the body, the center of gravity of the whole body and weight together is raised up to *I*; and then, as the line of direction *ID* falls without the base at *D*, the center of gravity *I* is not supported; and the whole body and weight tumble down together.

Hence appears the absurdity of people's rising hastily in a coach or boat when it is likely to overset: for, by that means they raise the center of gravity so far as to endanger throwing it quite out of the base; which if they do, they overset the vehicle effectually. Whereas, had they clapt down to the bottom, they would have brought the line of direction, and consequently the center of gravity, farther within the base, and by that means might have saved themselves.

The broader the base is, and the nearer the line of direction is to the middle or center of it, the more firmly does the body stand. On the contrary, the narrower the base, and the nearer the line of direction is to the side of it, the more easily may the body be overthrown: a less change of position being sufficient to remove the line of direction out of the base in the latter case than in the former. And hence it is, that a sphere is so easily rolled upon a horizontal plane; and that it is so difficult, if not impossible, to make things which are sharp pointed to stand upright on the point.—From what hath been said, it plainly appears that if the plane be inclined on which the heavy body is placed, the body will slide down upon the plane whilst the line of direction falls within the base; but it will tumble or roll down when that line falls without

 the

the base. Thus, the body *A* will only slide down the inclined plane *CD*, whilst the body *B* rolls down upon it. Fig. 4.

When the line of direction falls within the base of our feet, we stand; and most firmly when it is in the middle: but when it is out of that base, we immediately fall. And it is not only pleasing, but even surprizing, to reflect upon the various and unthought of methods and postures which we use to retain this position, or to recover it when it is lost. For this purpose we bend our body forward when we rise from a chair, or when we go up stairs: and for this purpose a man leans forward when he carries a burden on his back, and backward when he carries it on his breast; and to the right or left side as he carries it on the opposite side. A thousand more instances might be added.

The quantity of matter in all bodies is in exact proportion to their weights, bulk for bulk. Therefore, heavy bodies are as much more dense or compact than light bodies of the same bulk, as they exceed them in weight.

All bodies porous. All bodies are full of pores, or spaces void of matter: and in gold, which is the heaviest of all known bodies, there is perhaps a greater quantity of space than of matter. For the particles of heat and magnetism find an easy passage through the pores of gold; and even water itself has been forced through them. Besides, if we consider how easily the rays of light pass through so solid a body as glass, in all manner of directions, we shall find reason to believe that bodies are much more porous than is generally imagined.

The expansion of metals. All bodies are some way or other affected by heat; and all metallic bodies are expanded in length,

length, breadth, and thickneſs thereby.—The proportion of the expanſion of ſeveral metals, according to the beſt experiments I have been able to make with my pyrometer, is nearly thus; Iron and glaſs as 3, ſteel 4, copper 4 and one eighth, braſs 5, tin 6, lead 6 and one eighth. An iron rod 3 feet long is about one 70th part of an inch longer in ſummer than in winter.

The pyrometer. The pyrometer here mentioned being (for aught I know) of a new conſtruction, a deſcription of it may perhaps be agreeable to the reader.

Fig. 5. *AA* is a flat piece of mahogony, in which are fixed four braſs ſtuds *B*,*C*,*D*,*L*; and two pins, one at *F* and the other at *H*. On the pin *F* turns the crooked index *EI*, and upon the pin *H* the ſtraight index *GK*, againſt which a piece of watch-ſpring *R* bears gently, and ſo preſſes it towards the beginning of the ſcale *MN*, over which the point of that index moves. This ſcale is divided into inches and tenth parts of an inch: the firſt inch is marked 1000, the ſecond 2000, and ſo on. A bar of metal *O* is laid into notches in the top of the ſtuds *C* and *D*; one end of the bar bearing againſt the adjuſting ſcrew *P*, and the other end againſt the crooked index *EI*, at a 20th part of its length from its center of motion *F*.—Now it is plain, that however much the bar *O* lengthens, it will move that part of the index *EI* againſt which it bears juſt as far: but the crooked end of the ſame index, near *H*, being 20 times as far from the center of motion *F* as the point is againſt which the bar bears, it will move 20 times as far as the bar lengthens. And as this crooked end bears againſt the index *GK* at only a 20th part of the whole length *G* 8 from its center of

motion

motion *H*, the point *S* will move through 20 times the ſpace that the point of bearing near *H* does. Hence, as 20 multiplied by 20 produces 400, it is evident that if the bar lengthens but a 400th part of an inch, the point *S* will move a whole inch on the ſcale; and as every inch is divided into 10 equal parts, if the bar lengthens but the 10th part of the 400th part of an inch, which is only the 4000th part of an inch, the point *S* will move the tenth part of an inch, which is very perceptible.

To find how much a bar lengthens by heat, firſt lay it cold into the notches of the ſtuds, and turn the adjuſting ſcrew *P* until the ſpring *R* brings the point *S* of the index *GK* to the beginning of the diviſions of the ſcale at *M*: then, without altering the ſcrew any farther, take off the bar and rub it with a dry woollen cloth till it feels warm; and then, laying it on where it was, obſerve how far it puſhes the point *S* upon the ſcale by means of the crooked index *EI*; and the point *S* will ſhew exactly how much the bar has lengthened by the heat of rubbing. As the bar cools, the ſpring *R* bearing againſt the index *KG*, will cauſe its point *S* to move gradually back towards *M* in the ſcale: and when the bar is quite cold, the index will reſt at *M*, where it was before the bar was made warm by rubbing. The indexes have ſmall rollers under them at *I* and *K*; which, by turning round on the ſmooth wood as the indexes move, make their motions the eaſier, by taking off a great part of the friction, which would otherwiſe be on the pins *F* and *H*, and of the points of the indexes themſelves on the wood.

Magnetiſm.

Beſides the univerſal properties above-mentioned, there are bodies which have properties

C pecu-

peculiar to themſelves: ſuch as the loadſtone, in which the moſt remarkable are theſe; 1. it attracts iron and ſteel only. 2. It conſtantly turns one of its ſides to the north and another to the ſouth, when ſuſpended by a thread that does not twiſt. 3. It communicates all its properties to a piece of ſteel when rubbed upon it, without loſing any itſelf.

According to Dr. *Helſham*'s experiments, the attraction of the loadſtone decreaſes as the ſquare of the diſtance increaſes. Thus, if a loadſtone be ſuſpended at one end of a balance, and counterpoiſed by weights at the other end, and a flat piece of iron be placed beneath it, at the diſtance of four tenths of an inch, the ſtone will immediately deſcend and adhere to the iron. But if the ſtone be again removed to the ſame diſtance, and as many grains be put into the ſcale at the other end as will exactly counterbalance the attraction, then, if the iron be brought twice as near the ſtone as before, that is, only two tenth parts of an inch from it, there muſt be four times as many grains put into the ſcale as before, in order to be a juſt counterbalance to the attractive force, or to hinder the ſtone from deſcending and adhering to the iron. So, if four grains will do in the former caſe, there muſt be ſixteen in the latter. But from ſome later experiments, made with the greateſt accuracy, it is found that the force of magnetiſm decreaſes in a ratio between the reciprocal of the ſquare and the reciprocal of the cube of the diſtance; approaching to the one or the other, as the magnitudes of the attracting bodies are varied.

Electricity. Several bodies, particularly amber, glaſs, jet, ſealing-wax, agate, and almoſt all precious ſtones, have a peculiar property of attracting

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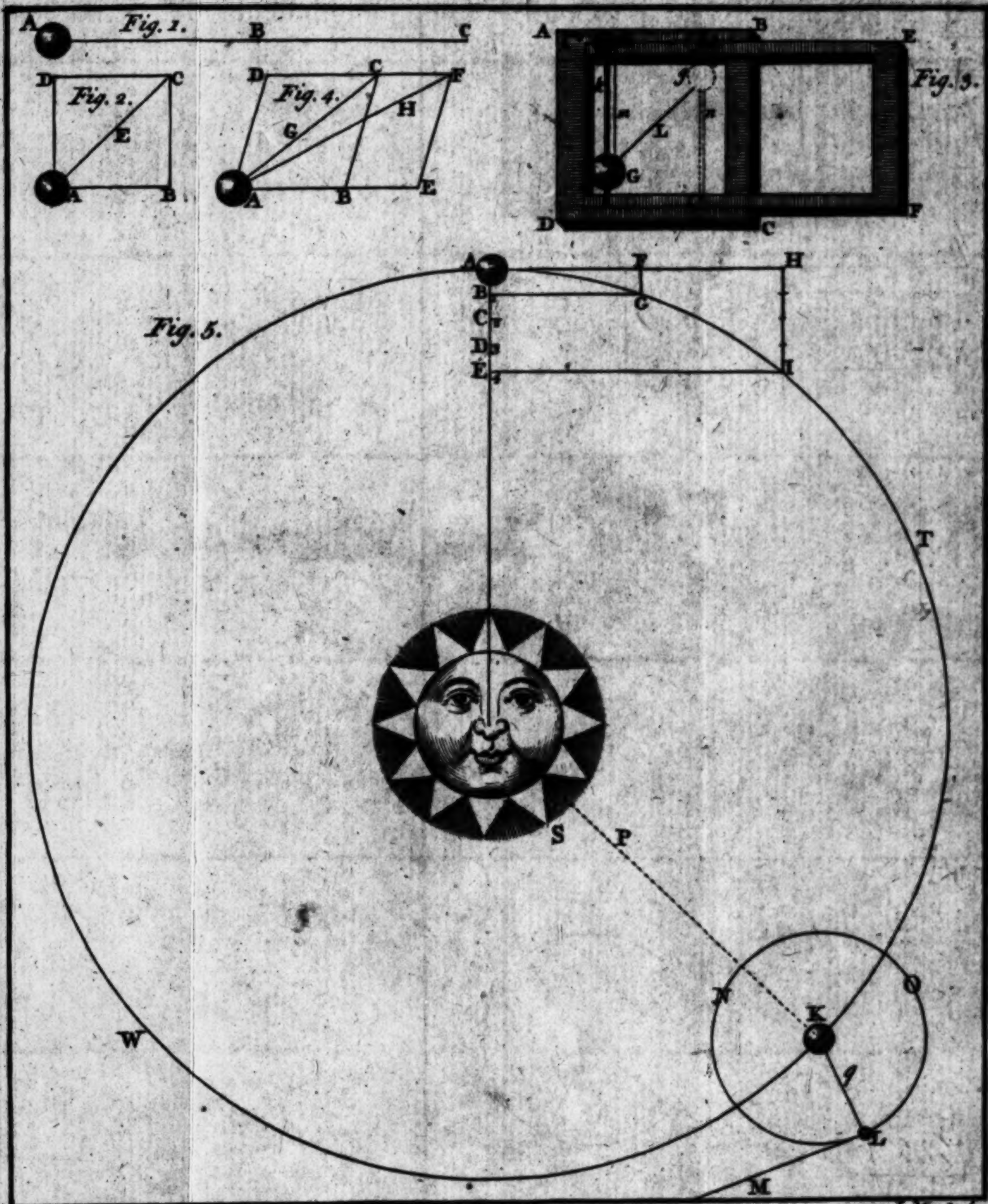
PLATE II.



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and repelling light bodies when heated by rubbing. This is called *electrical attraction*, in which the chief things to be observed are, 1. if a glaſs tube about an inch and a half diameter, and two or three feet long, be heated by rubbing, it will alternately attract and repel all light bodies at the diſtance of 10 or 15 inches. 2. It does not attract by being heated without rubbing. 3. Any light body being once repelled by the tube, will never be attracted again till it has touched ſome other body. 4. If the tube be rubbed by a moiſt hand, or any thing that is wet, it totally deſtroys the electricity. 5. Any body except air, being interpoſed, ſtops the electricity. 6. The tube attracts ſtronger when rubbed over with bees-wax, and then with a dry woollen cloth. 7. When it is well rubbed, if a finger be brought near it, at about the diſtance of half an inch, the effluvia will ſnap againſt the finger, and make a little crackling noiſe; and if this be performed in a dark place, there will appear a little flaſh of light.

L E C T. II.

Of central forces.

Motion or reſt equally indifferent to all bodies.

Plate II. Fig. 1.

WE have already mentioned it as a neceſſary conſequence ariſing from the deadneſs or inactivity of matter, that all bodies endeavour to continue in the ſtate they are in, whether of reſt or motion. If the body *A* were placed in any part of free ſpace, where nothing either draws or impels it any way, it would for ever remain in that part of ſpace, becauſe it could have no tendency of itſelf to remove any way from thence. If it receives a ſingle impulſe

pulse any way, as suppose from *A* towards *B*, it will go on in that direction; for, of itself it could never swerve from a right line, nor stop its course.—When it has gone through the space *AB*, and met with no resistance, its velocity will be the same at *B* as it was at *A*: and this velocity, in as much more time, will carry it through as much more space, from *B* to *C*; and so on for ever. Therefore, when we see a body in motion, we conclude that some other substance must have given it that motion; and when we see a body fall from motion to rest, we conclude that some other body or cause stopt it.

All motion naturally rectilineal.

As all motion is naturally rectilineal, it appears, that a bullet projected by the hand, or shot from a cannon, would for ever continue to move in the same direction it received at first, if no other power diverted its course. Therefore, when we see a body move in a curve of any kind whatever, we conclude it must be acted upon by two powers at least; one putting it in motion, and another drawing it off from the rectilineal course it would otherwise have continued to move in: and whenever that power, which bent the motion of the body from a straight line into a curve, ceases to act, the body will again move on in a straight line touching that point of the curve in which it was when the action of that power ceased. For example, a pebble moved round in a sling ever so long a time, will fly off the moment it is set at liberty, by slipping one end of the sling-cord: and will go on in a line touching the circle it described before: which line would actually be a straight one, if the earth's attraction did not affect the pebble, and bring it down to the ground. This shews that the natural tendency of the pebble, when put into

into motion, is to continue moving in a ſtraight line, although by the force that moves the ſling it be made to revolve in a circle.

The change of motion produced is in proportion to the force impreſſed: for the effects of natural cauſes are always proportionate to the force or power of thoſe cauſes. **The effects of combined forces.**

By theſe laws it is eaſy to prove that a body will deſcribe the diagonal of a ſquare or parallelogram, by two forces conjoined, in the ſame time that it would deſcribe either of the ſides, by one force ſingly. Thus, ſuppoſe the body *A* to repreſent a ſhip at ſea; and that it is drove by the wind, in the right line *AB*, with ſuch a force as would carry it uniformly from *A* to *B* in a minute: then, ſuppoſe a ſtream or current of water running in the direction *AD*, with ſuch a force as would carry the ſhip through an equal ſpace from *A* to *D* in a minute. By theſe two forces, acting together at right angles to each other, the ſhip will deſcribe the line *AEC* in a minute: which line (becauſe the forces are equal and perpendicular to each other) will be the diagonal of an exact ſquare. To confirm this law by an experiment, let there be a wooden ſquare *ABCD* ſo contrived, as to have the part *BEFC* made to draw out or puſh into the ſquare at pleaſure. To this part let the pulley *H* be joined, ſo as to turn freely on an axis, which will be at *H* when the piece is puſhed in, and at *b* when it is drawn out. To this part let the ends of a ſtraight wire *k* be fixed, ſo as to move along with it, under the pulley; and let the ball *G* be made to ſlide eaſily on the wire. A thread *m* is fixed to this ball, and goes over the pulley to *I*; by this thread the ball may be drawn up on the wire, parallel to the ſide *AD*, when the

Fig. 2.

Fig. 3.

part *BEFC* is pushed as far as it will go into the square. But, if this part be drawn out, it will carry the ball along with it, parallel to the bottom of the square *DC*. By this means, the ball *G* may either be drawn perpendicularly upward by pulling the thread *m*, or moved horizontally along by pulling out the part *BEFC*, in equal times, and through equal spaces; each power acting equally and separately upon it. But if, when the ball is at *G*, the upper end of the thread be tied to the pin *I*, in the corner *A* of the fixed square, and the moveable part *BEFG* be drawn out, the ball will then be acted upon by both the powers together: for it will be drawn up by the thread towards the top of the square, and at the same time carried with its wire *k* towards the right hand *BC*, moving all the while in the diagonal line *L*; and will be found at *g* when the sliding part is drawn out as far as it was before; which then will have caused the thread to draw up the ball to the top of the inside of the square, just as high as it was before, when drawn up singly by the thread without moving the sliding part.

If the acting forces are equal, but at oblique angles to each other, so will the sides of the parallelogram be: and the diagonal run through by the moving body will be longer or shorter, according as the obliquity is greater or smaller. Thus, if two equal forces act conjointly upon the
Fig. 4. body *A*, one having a tendency to move it through the space *AB* in the same time that the other has a tendency to move it through an equal space *AD*; it will describe the diagonal *AGC* in the same time that either of the single forces would have caused it to describe either of the sides. If one of the forces be greater than the other,

other, then one side of the parallelogram will be so much longer than the other. For, if one force singly would carry the body through the space *AE*, in the same time that the other would have carried it through the space *AD*, the joint action of both will carry it in the same time through the space *AHF*, which is the diagonal of the oblique parallelogram *ADEF*.

If both forces act upon the body in such a manner, as to move it uniformly, the diagonal described will be a straight line; but if one of the forces acts in such a manner as to make the body move faster and faster as it goes forward, then the line described will be a curve. And this is the case of all bodies which are projected in rectilineal directions, and at the same time acted upon by the power of gravity; which has a constant tendency to accelerate their motions in the direction wherein it acts.

From the uniform projectile motion of bodies in straight lines, and the universal power of gravity or attraction, arises the curvilineal motion of all the heavenly bodies. If the body *A* be projected along the straight line *AFH* in open space, where it meets with no resistance, and is not drawn aside by any power, it will go on for ever with the same velocity, and in the same direction. But if, at the same moment the projectile force is given it at *A*, the body *S* begins to attract it with a force duly adjusted *, and perpendicular to its motion at *A*, it will then be drawn from the straight line *AFH*, and forced

The laws of the planetary motions.

Fig. 5.

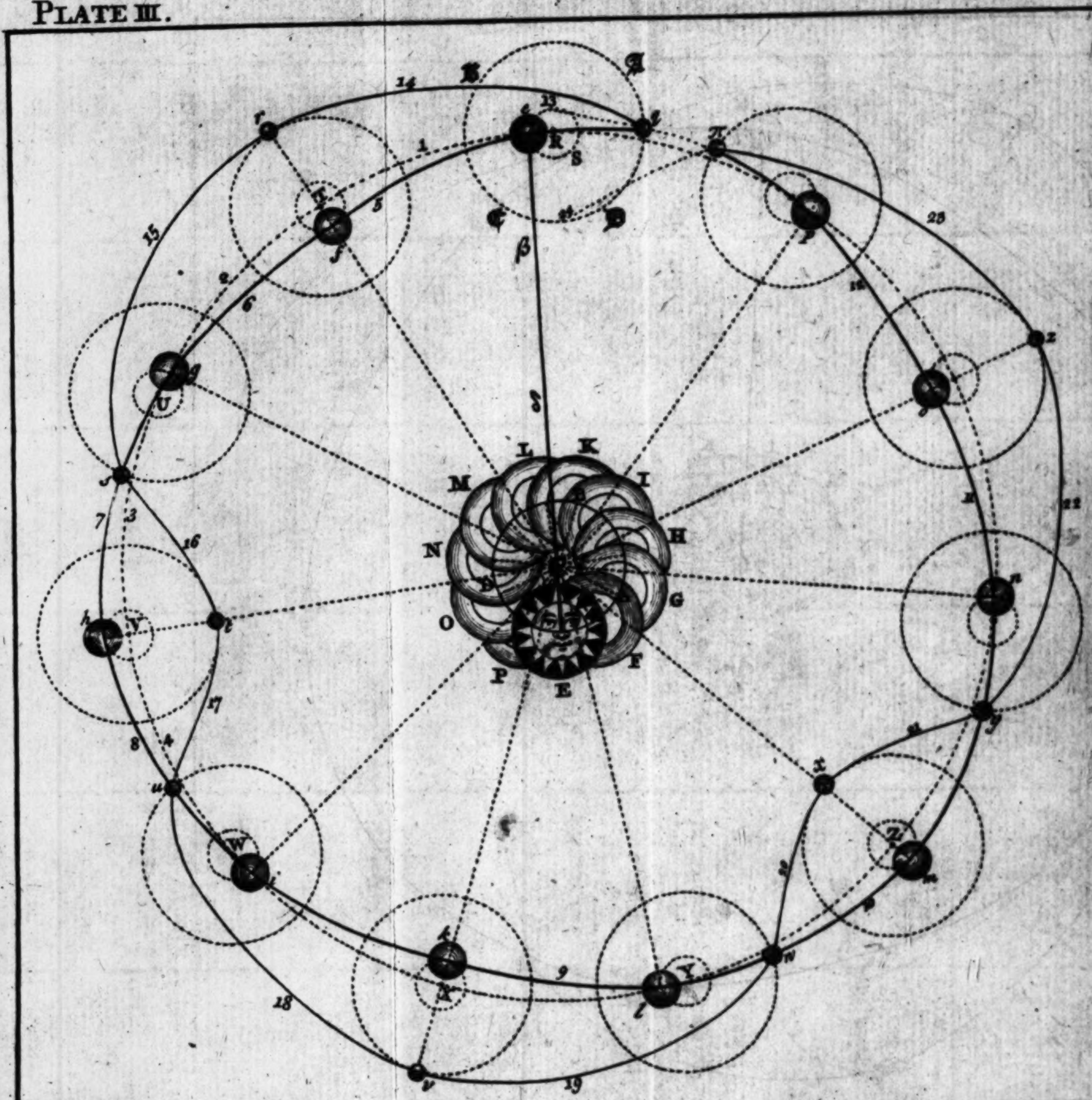
* To make the projectile force a just balance to the gravitating power, so as to keep the planet moving in a circle, it must give such a velocity as the planet would acquire by gravity when it had fallen through half the semidiameter of that circle.

to revolve about *S* in the circle *ATW*; in the ſame manner, and by the ſame law, that a pebble is moved round in a ſling. And if, when the body is in any part of its orbit (as ſuppoſe at *K*) a ſmaller body as *L*, within the ſphere of attraction of the body *K*, be projected in the right line *LM*, with a force duly adjuſted, and perpendicular to the line of attraction *LK*; then, the ſmall body *L* will revolve about the large body *K* in the orbit *NO*, and accompany it in its whole courſe round the yet larger body *S*. But then, the body *K* will no longer move in the circle *ATW*; for that circle will now be deſcribed by the common center of gravity between *K* and *L*. Nay, even the great body *S* will not keep in the center; for it will be the common center of gravity between all the three bodies *S*, *K*, and *L*, that will remain immoveable there. So, if we ſuppoſe *S* and *K* connected by a wire *P* that has no weight, and *K* and *L* connected by a wire *q* that has no weight, the common center of gravity of all theſe three bodies will be a point in the wire *P* near *S*; which point being ſupported, the bodies will be all in *equilibrio* as they move round it. Though indeed, ſtrictly ſpeaking, the common center of gravity of all the three bodies will not be in the wire *P* but when theſe bodies are all in a right line. Here, *S* may repreſent the ſun, *K* the earth, and *L* the moon.

In order to form an idea of the curves deſcribed by two bodies revolving about their common center of gravity, whilſt they themſelves with a third body are in motion round the common center of gravity of all the three; let us firſt ſuppoſe *E* to be the ſun, and *e* the earth going round him without any moon; and their

See Plate III.

PLATE III.



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their moving forces regulated as above. In this case, whilst the earth goes round the sun in the dotted circle *RTUWX*, &c. the sun will go round the circle *ABD*, whose center *C* is the common center of gravity between the sun and earth: the right line β δ representing the mutual attraction between them, by which they are as firmly connected as if they were fixed at the two ends of an iron bar strong enough to hold them. So, when the earth is at *e*, the sun will be at *E*; when the earth is at *T*, the sun will be at *F*; and when the earth is at *g*, the sun will be at *G*, &c.

The curves described by bodies revolving about their common center of gravity.

Now, let us take in the moon *q* (at the top of the figure) and suppose the earth to have no progressive motion about the sun; in which case, whilst the moon revolves about the earth in her orbit 𝔄𝔅ℭ𝔇, the earth will revolve in the circle *S* 13, whose center *R* is the common center of gravity of the earth and moon; they being connected by the mutual attraction between them in the same manner as the earth and sun are.

But the truth is, that whilst the moon revolves about the earth, the earth is in motion about the sun: and now, the moon will cause the earth to describe an irregular curve, and not a true circle, round the sun; it being the common center of gravity of the earth and moon that will then describe the same circle which the earth would have moved in, if it had not been attended by a moon. For, supposing the moon to describe a quarter of her progressive orbit about the earth in the time that the earth moves from *e* to *f*; it is plain, that when the earth comes to *f*, the moon will be found at *r*; in which time, their common center of gravity will

will have described the dotted arc *R* 1 *T*, the earth the curve *R* 5 *f*, and the moon the curve *q* 14 *r*. In the time that the moon describes another quarter of her orbit, the center of gravity of the earth and moon will describe the dotted arc *T* 2 *U*, and the earth the curve *f* 6 *g*, and the moon the curve *r* 15 *s*, and so on—And thus, whilst the moon goes once round the earth in her progressive orbit, their common center of gravity describes the regular portion of a circle *R* 1 *T* 2 *U* 3 *V* 4 *W*, the earth the irregular curve *R* 5 *f* 6 *g* 7 *h* 8 *i*, and the moon the yet more irregular curve *q* 14 *r* 15 *s* 16 *t* 17 *u*; and then, the same kind of tracks over again.

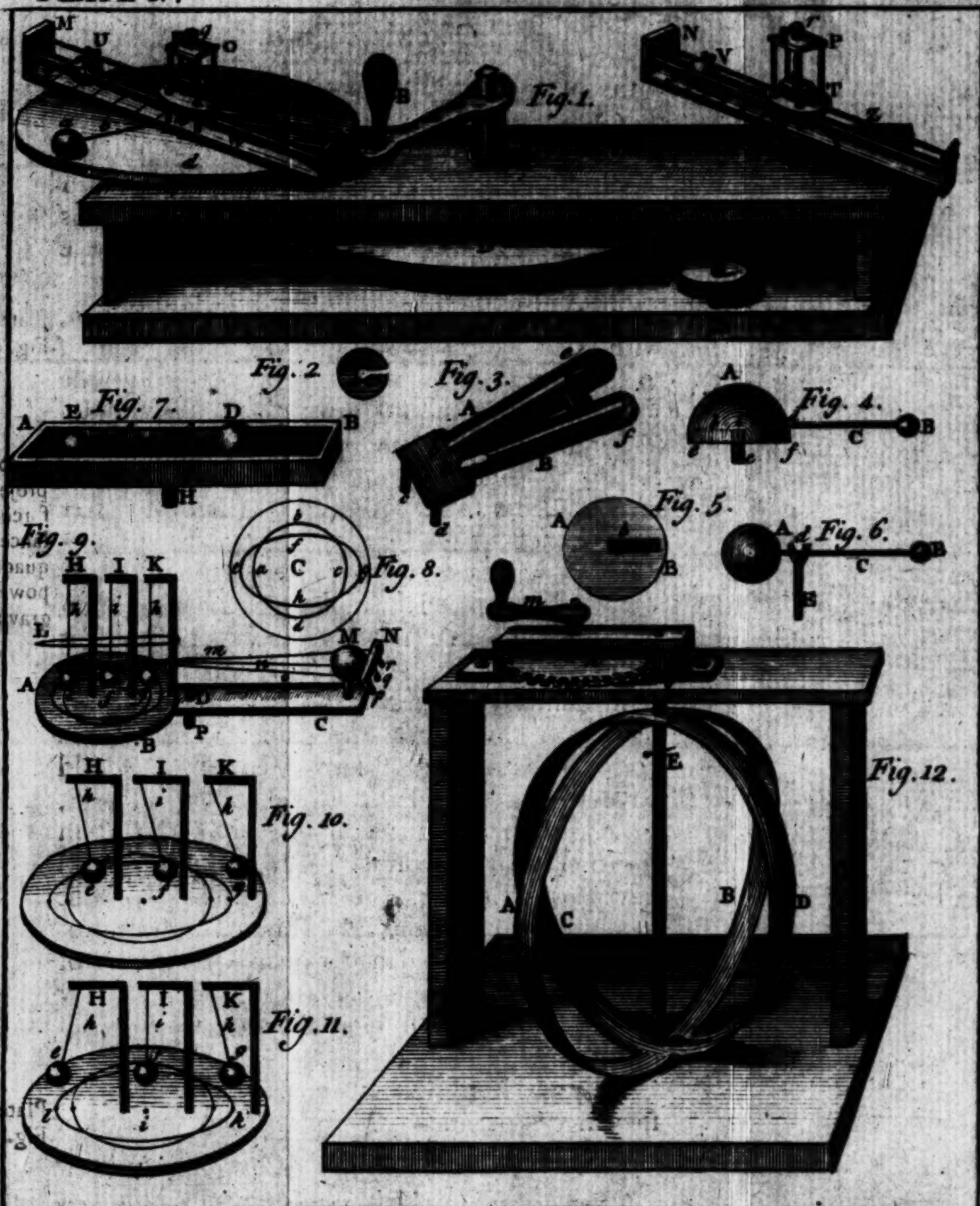
The center of gravity of the earth and moon is 6000 miles from the earth's center towards the moon; therefore the circle *S* 13 which the earth describes round that center of gravity (in every course of the moon round her orbit) is 12000 miles in diameter. Consequently the earth is 12,000 miles nearer the sun at the time of full moon than at the time of new. [See the earth at *f* and at *h*.]

To avoid confusion in so small a figure, we have supposed the moon to go only twice and a half round the earth, in the time that the earth goes once round the sun: it being impossible to take in all the revolutions which she makes in a year, and to give a true figure of her path, unless we should make the semidiameter of the earth's orbit at least 84 inches; and then, the proportional semidiameter of the moon's orbit would be only a quarter of an inch.—For a true figure of the moon's path, I refer the reader to my Treatise of Astronomy.

If the moon made any compleat number of revolutions about the earth in the time that the earth makes one revolution about the sun, the

paths

PLATE IV.



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paths of the ſun and moon would return into themſelves at the end of every year; and ſo be the ſame over again: but they return not into themſelves in leſs than 19 years nearly; in which time, the earth makes nearly 19 revolutions about the ſun, and the moon 235 about the earth.

If the planet *A* be attracted towards the ſun, with ſuch a force as would make it fall from *A* to *B*, in the time that the projectile impulſe would have carried it from *A* to *F*, it will deſcribe the arc *AG* by the combined action of theſe forces, in the ſame time that the former would have cauſed it to fall from *A* to *B*, or the latter have carried it from *A* to *F*. But, if the projectile force had been twice as great, that is, ſuch as would have carried the planet from *A* to *H*, in the ſame time that now, by the ſuppoſition, it carries it only from *A* to *F*; the ſun's attraction muſt then have been four times as ſtrong as formerly, to have kept the planet in the circle *ATW*; that is, it muſt have been ſuch as would have cauſed the planet to fall from *A* to *E*, which is four times the diſtance of *A* from *B*, in the time that the projectile force ſingly would have carried it from *A* to *H*, which is only twice the diſtance of *A* from *F**. Thus, a double projectile force will balance a quadruple power of gravity in the ſame circle; as appears plain by the figure, and ſhall ſoon be confirmed by an experiment.

Plate II. Fig. 5.

A double projectile force balances a quadruple power of gravity.

The whirling-table is a machine contrived for ſhewing experiments of this nature. *AA* is a ſtrong frame of wood, *B* a winch or handle

Plate IV. Fig. 1.

* Here the arcs *AG*, *AI* muſt be ſuppoſed to be very ſmall; otherwiſe *AE*, which is equal to *HI*, will be more than quadruple to *AB*, which is equal to *FG*.

fixed

The whirling-table described.

fixed on the axis *C* of the wheel *D*, round which is the catgut ſtring *F*, which alſo goes round the ſmall wheels *G* and *K*, croſſing between them and the great wheel *D*. On the upper end of the axis of the wheel *G*, above the frame, is fixed the round board *d*, to which the bearer *MSX* may be faſtened occaſionally, and removed when it is not wanted. On the axis of the wheel *H* is fixed the bearer *NTZ*: and it is eaſy to ſee that when the winch *B* is turned, the wheels and bearers are put into a whirling motion.

Each bearer has two wires, *W*, *X*, and *Y*, *Z*, fixed and ſcrewed tight into them at the ends by nuts on the outſide. And when theſe nuts are unſcrewed, the wires may be drawn out in order to change the balls *U* and *V*, which ſlide upon the wires by means of braſs loops fixed into the balls, which keep the balls up from touching the wood below them. A ſtrong ſilk line goes through each ball, and is fixed to it at any length from the center of the bearer to its end, as occaſion requires, by a nut-ſcrew at the top of the ball; the ſhank of the ſcrew goes into the center of the ball, and preſſing the line againſt the under ſide of the hole that it goes through.—The line goes from the ball, and under a ſmall pulley fixt in the middle of the bearer; then up through a ſocket in the round plate (ſee *S* and *T*) in the middle of each bearer; then through a ſlit in the middle of the ſquare top (*O* and *P*) of each tower, and going over a ſmall pulley on the top, comes down again the ſame way, and is at laſt faſtened to the upper end of the ſocket fixt in the middle of the above-mentioned round plate. Theſe plates *S* and *T* have each four round holes near their edges for letting them

ſlide

ſlide up and down upon the wires which make the corner of each tower. The balls and plates being thus connected, each by its particular line, it is plain that if the balls be drawn outward, or towards the ends *M* and *N* of their reſpective bearers, the round plates *S* and *T* will be drawn up to the top of their reſpective towers *O* and *P*.

There are ſeveral braſs weights, ſome of two ounces, ſome of three, and ſome of four, to be occaſionally put within the towers *O* and *P*, upon the round plates *S* and *T*: each weight having a round hole in the middle of it, for going upon the ſockets or axes of the plates, and is ſlit from the edge to the hole, for allowing it to be ſlipt over the foreſaid line which comes from each ball to its reſpective plate.

The experiments to be made by this machine are,

1. Take away the bearer *MX*, and take the ivory ball *a*, to which the line or ſilk cord *b* is faſtened at one end; and having made a loop on the other end of the cord, put the loop over a pin fixt in the center of the board *d*. Then, turning the winch *B* to give the board a whirling motion, you will ſee that the ball does not immediately begin to move with the board, but, on account of its inactivity, it endeavours to continue in the ſtate of reſt which it was in before.— Continue turning, until the board communicates an equal degree of motion with its own to the ball, and then turning on, you will perceive that the ball will remain upon one part of the board, keeping the ſame velocity with it, and having no relative motion upon it, as is the caſe with every thing that lies looſe upon the plane ſurface of the earth, which having the motion of the earth communicated to it, never endeavours to remove from

Fig. 1.

The propenſity of matter to keep the ſtate it is in.

from that place. But ſtop the board ſuddenly by hand, and the ball will go on, and continue to revolve upon the board, until the friction thereof ſtops its motion: which ſhows, that matter being once put into motion, would continue to move for ever, if it met with no reſiſtance. In like manner, if a perſon ſtands upright in a boat before it begins to move, he can ſtand firm; but the moment the boat ſets off, he is in danger of falling towards that place which the boat departs from: becauſe, as matter, he has no natural propenſity to move. But when he acquires the motion of the boat, let it be ever ſo ſwift, if it be ſmooth and uniform, he will ſtand as upright and firm as if he was on the plain ſhore; and if the boat ſtrike againſt any obſtacle, he will fall towards that obſtacle; on account of the propenſity he has, as matter, to keep the motion which the boat has put him into.

2. Take away this ball, and put a longer cord to it, which may be put down through the hollow axis of the bearer MX, and wheel G, and fix a weight to the end of the cord below the machine; which weight, if left at liberty, will draw the ball from the edge of the whirling-board to its center.

Bodies moving in orbits have a tendency to fly out of theſe orbits.

Draw off the ball a little from the center, and turn the winch; then the ball will go round and round with the board, and will gradually fly off farther and farther from the center, and raiſe up the weight below the machine: which ſhows that all bodies revolving in circles have a tendency to fly off from theſe circles, and muſt have ſome power acting upon them from the center of motion, to keep them from flying off. Stop the machine, and the ball will continue to revolve for

for some time upon the board; but as the friction gradually stops its motion, the weight acting upon it will bring it nearer and nearer to the center in every revolution, until it brings it quite thither. This shews, that if the planets met with any resistance in going round the sun, its attractive power would bring them nearer and nearer to it in every revolution, until they fell into it.

3. Take hold of the cord below the machine with one hand, and with the other throw the ball upon the round board as it were at right angles to the cord, by which means it will go round and round upon the board. Then observing with what velocity it moves, pull the cord below the machine, which will bring the ball nearer to the center of the board, and you will see that the nearer the ball is drawn to the center, the faster it will revolve; as those planets which are nearest the sun revolve faster than those which are more remote; and not only go round sooner, because they describe smaller circles, but even move faster in every part of their respective circles.

Bodies move faster in small orbits than in large ones.

4. Take away this ball, and apply the bearer *MX*, whose center of motion is in its middle at *w*, directly over the center of the whirling-board *d*. Then put two balls (*V* and *U*) of equal weights upon their bearing wires, and having fixed them at equal distances from their respective centers of motion *w* and *x* upon their silk cords, by the screw nuts, put equal weights in the towers *O* and *P*. Lastly, put the catgut strings *E* and *F* upon the grooves *G* and *H* of the small wheels, which being of equal diameters, will give equal velocities to the bearers above, when the winch *B* is turned: and the balls *U* and *V* will

Their centrifugal forces shewn.

fly

fly off towards M and N; and will raiſe the weights in the towers at the ſame inſtant. This ſhews, that when bodies of equal quantities of matter revolve in equal circles with equal velocities, their centrifugal forces are equal.

5. Take away theſe equal balls, and inſtead of them, put a ball of ſix ounces into the bearer MX, at a ſixth part of the diſtance wz from the center, and put a ball of one ounce into the oppoſite bearer, at the whole diſtance xy, which is equal to wz from the center of the bearer; and fix the balls at theſe diſtances on their cords, by the ſcrew nuts at top; and then the ball U, which is ſix times as heavy as the ball V, will be at only a ſixth part of the diſtance from its center of motion; and conſequently will revolve in a circle of only a ſixth part of the circumference of the circle in which V revolves. Now, let any equal weights be put into the towers, and the machine be turned by the winch; which (as the catgut ſtring is on equal wheels below) will cauſe the balls to revolve in equal times; but V will move ſix times as faſt as U, becauſe it revolves in a circle of ſix times its radius; and both the weights in the towers will riſe at once. This ſhews, that the centrifugal forces of revolving bodies (or their tendencies to fly off from the circles they deſcribe) are in direct proportion to their quantities of matter multiplied into their reſpective velocities; or into their diſtances from the centers of their reſpective circles. For, ſuppoſing U, which weighs ſix ounces, to be two inches from its center of motion w, the weight multiplied by the diſtance is 12: and ſuppoſing V, which weighs only one ounce, to be 12 inches diſtant from the center of motion x, the weight 1 ounce multiplied by the diſtance 12 inches is

is 12. And as they revolve in equal times, their velocities are as their distances from the center, namely, as 1 to 6.

If these two balls be fixed at equal distances from their respective centers of motion, they will move with equal velocities; and if the tower *O* has 6 times as much weight put into it as the tower *P* has, the balls will raise their weight exactly at the same moment. This shews that the ball *U* being six times as heavy as the ball *V*, has six times as much centrifugal force, in describing an equal circle with an equal velocity.

A double velocity in the same circle, is a balance to a quadruple power of gravity.

6. If bodies of equal weights revolve in equal circles with unequal velocities, their centrifugal forces are as the squares of the velocities. To prove this law by an experiment, let two balls *U* and *V* of equal weights be fixed on their cords at equal distances from their respective centers of motion *w* and *x*; and then let the catgut string *E* be put round the wheel *K* (whose circumference is only one half of the circumference of the wheel *H* or *G*) and over the pulley *s* to keep it tight; and let four times as much weight be put into the tower *P*, as in the tower *O*. Then turn the winch *B*, and the ball *V* will revolve twice as fast as the ball *U* in a circle of the same diameter, because they are equidistant from the centers of the circles in which they revolve; and the weights in the towers will both rise at the same instant, which shews that a double velocity in the same circle will exactly balance a quadruple power of attraction in the center of the circle. For the weights in the towers may be considered as the attractive forces in the centers, acting upon the revolving balls; which,

moving in equal circles, is the ſame thing as if they both moved in one and the ſame circle.

Ke:ler's Problem. 7. If bodies of equal weights revolve in unequal circles, in ſuch a manner that the ſquares of the times of their going round are as the cubes of their diſtances from the centers of the circles they deſcribe; their centrifugal forces are inverſely as the ſquares of their diſtances from thoſe centers. For, the catgut ſtring remaining as in the laſt experiment, let the diſtance of the ball *V* from the center *x* be made equal to two of the croſs diviſions on its bearer; and the diſtance of the ball *U* from the center *w* be three and a ſixth part; the balls themſelves being of equal weights, and *V* making two revolutions by turning the winch, in the time that *U* makes one: ſo that if we ſuppoſe the ball *V* to revolve in one moment, the ball *U* will revolve in two moments, the ſquares of which are one and four: for the ſquare of 1 is only 1, and the ſquare of 2 is 4; therefore the ſquare of the period or revolution of the ball *V*, is contained four times in the ſquare of the period of the ball *U*. But the diſtance of *V* is 2, the cube of which is 8, and the diſtance of *U* is $3\frac{1}{6}$, the cube of which is 32 very nearly; in which 8 is contained four times; and therefore, the ſquares of the periods of *V* and *U* are to one another as the cubes of their diſtances from *x* and *w*, which are the centers of their reſpective circles. And if the weight in the tower *O* be four ounces, equal to the ſquare of 2, the diſtance of *V* from the center *x*; and the weight in the tower *P* be 10 ounces, nearly equal to the ſquare of $3\frac{1}{6}$, the diſtance of *U* from *w*; it will be found upon turning the machine by the winch, that the balls *U* and *V* will raiſe their reſpective weights at very nearly

nearly the ſame inſtant of time. Which confirms that famous propoſition of KEPLER, viz. that the ſquares of the periodical times of the planets round the ſun are in proportion to the cubes of their diſtances from him; and that the ſun's attraction is inverſely as the ſquare of the diſtance from his center: that is, at twice the diſtance, his attraction is four times leſs; and thrice the diſtance, nine times leſs; at four times the diſtance, ſixteen times leſs; and ſo on, to the remoteſt part of the ſyſtem.

8. Take off the catgut ſtring *E* from the great wheel *D* and the ſmall wheel *H*, and let the ſtring *F* remain upon the wheels *D* and *G*. Take away alſo the bearer *MX* from the whirling-board *d*, and inſtead thereof put the machine *AB* upon it, fixing this machine to the center of the board by the pins *c* and *d*, in ſuch a manner, that the end *ef* may riſe above the board to an angle of 30 or 40 degrees. In the upper ſide of this machine there are two glaſs tubes *a* and *b*, cloſe ſtopt at both ends; and each tube is about three quarters full of water. In the tube *a* is a little quickſilver, which naturally falls down to the end *a* in the water, becauſe it is heavier than its bulk of water; and on the tube *b* is a ſmall cork which floats on the top of the water at *e*, becauſe it is lighter; and it is ſmall enough to have liberty to riſe or fall in the tube. While the board *b* with this machine upon it continues to reſt, the quickſilver lies at the bottom of the tube *a*, and the cork floats on the water near the top of the tube *b*. But, upon turning the winch, and putting the machine in motion, the contents of each tube will fly off towards the uppermoſt ends (which are fartheſt from the center of motion) the heavieſt

Fig. 3.

The abſurdity of the Carteſian vortexes.

with the greatest force. Therefore the quicksilver in the tube *a* will fly off quite to the end *f*, and occupy its bulk of space there, excluding the water from that place, because it is lighter than quicksilver; but the water in the tube *b* flying off to its higher end *e*, will exclude the cork from that place, and cause the cork to descend towards the lowermost end of the tube, where it will remain upon the lowest end of the water near *b*; for the heavier body having the greater centrifugal force, will therefore possess the uppermost part of the tube; and the lighter body will keep between the heavier and the lowermost part.

This demonstrates the absurdity of the Cartesian doctrine of the planets moving round the sun in vortexes: for, if the planet be more dense or heavy than its bulk of the vortex, it will fly off therein, farther and farther from the sun; if less dense, it will come down to the lowest part of the vortex, at the sun: and the whole vortex itself must be surrounded with something like a great wall, otherwise it would fly quite off, planets and all together.—But while gravity exists, there is no occasion for such vortexes; and when it ceases to exist, a stone thrown upwards will never return to the earth again.

If one body moves round another, both of them must move round their common center of gravity.

9. If a body be so placed on the whirling-board of the machine (Fig. 1.) that the center of gravity of the body be directly over the center of the board, and the board be put into ever so rapid a motion by the winch *B*, the body will turn round with the board, but will not remove from the middle of it; for, as all parts of the body are in *equilibrio* round its center of gravity, and the center of gravity is at rest in the center of motion, the centrifugal force of all parts of the

the body will be equal at equal distances from its center of motion, and therefore the body will remain in its place. But if the center of gravity be placed ever so little out of the center of motion, and the machine be turned swiftly round, the body will fly off towards that side of the board on which its center of gravity lies. Thus, if the wire *C* with its little ball *B* be taken away from the demi-globe *A*, and the flat side *ef* of this demi-globe be laid upon the whirling-board of the machine, so that their centers may coincide; if then the board be turned ever so quick by the winch, the demi-globe will remain where it was placed. But if the wire *C* be screwed into the demi-globe at *d*, the whole becomes one body, whose center of gravity is now at or near *d*. Let the pin *c* be fixed in the center of the whirling-board, and the deep groove *b* cut in the flat side of the demi-globe be put upon the pin, so as the pin may be in the center of *A* [See Fig. 5. where this groove is represented at *b*] and let the whirling-board be turned by the winch, which will carry the little ball *B* (Fig. 4.) with its wire *C*, and the demi-globe *A*, all round the center-pin *ci*; and then, the centrifugal force of the little ball *B*, which weighs only one ounce, will be so great, as to draw off the demi-globe *A*, which weighs two pounds, until the end of the groove at *e* strikes against the pin *c*, and so prevents the demi-globe *A* from going any farther: otherwise, the centrifugal force of *B* would have been great enough to have carried *A* quite off the whirling-board. Which shews, that if the sun were placed in the very center of the orbits of the planets, it could not possibly remain there; for the centrifugal forces of the planets would carry them quite off, and the sun

Fig. 4.

Fig. 5.

with them; especially when several of them happened to be in any one quarter of the heavens. For the sun and planets are as much connected by the mutual attraction that subsists between them, as the bodies *A* and *B* are by the wire *C* which is fixed into them both. And even if there were but one single planet in the whole heavens to go round ever so large a sun in the center of its orbit, its centrifugal force would soon carry off both itself and the sun. For, the greatest body placed in any part of free space could be easily moved: because if there were no other body to attract it, it could have no weight or gravity of itself; and consequently, though it could have no tendency of itself to remove from that part of space, yet it might be very easily moved by any other substance.—And perhaps it was this consideration which made the celebrated ARCHIMEDES say, that if he had a proper place at some distance from the earth whereon to fix his machinery, he could move the whole earth.

10. As the centrifugal force of the light body *B* will not allow the heavy body *A* to remain in the center of motion, even though it be 24 times as heavy as *B*; let us now take the ball *A* (Fig. 6.) which weighs 6 ounces, and connect it by the wire *C* with the ball *B*, which weighs only one ounce; and let the fork *E* be fixed into the center of the whirling-board: then hang the balls upon the fork by the wire *C* in such a manner, that they may exactly balance each other; which will be when the center of gravity between them, in the wire at *d*, is supported by the fork. And this center of gravity is as much nearer to the center of the ball *A*, than to the center of the ball *B*, as *A* is heavier than *B*, allowing for the weight of the wire on each side of the fork.

Fig. 6.

This

This done, let the machine be put into motion by the winch; and the balls *A* and *B* will go round their common center of gravity *d*, keeping their balance, becaufe either will not allow the other to fly off with it. For, fuppofing the ball *B* to be only one ounce in weight, and the ball *A* to be fix ounces; then, if the wire *C* were equally heavy on each fide of the fork, the center of gravity *d* would be fix times as far from the center of the ball *B* as from the ball *A*, and confequently *B* will revolve with a velocity fix times as great as *A* does; which will give *B* fix times as much centrifugal force as any fingle ounce of *A* has: but then, as *B* is only one ounce, and *A* fix ounces, the whole centrifugal force of *A* will exactly balance the whole centrifugal force of *B*: and therefore, each body will detain the other fo as to make it keep in its circle. This fhews that the fun and planets muft all move round the common center of gravity of the whole fyftem, in order to preferve that juft balance which takes place among them. For, the planets being as unactive and dead as the above balls, they could no more have put themfelves into motion than thefe balls can; nor have kept in their orbits without being balanced at firft with the greateft degree of exactnefs upon their common center of gravity, by the Almighty hand that made them and put them in motion.

Perhaps it may be here afked, that fince the center of gravity between thefe balls muft be fupported by the fork *E* in this experiment, what prop it is that fupports the center of gravity of the folar fyftem, and confequently bears the weight of all the bodies in it; and by what is the prop itfelf fupported? The anfwer is eafy and plain; for the center of gravity of our balls

muſt be ſupported, becauſe they gravitate towards the earth, and would therefore fall to it: but as the ſun and planets gravitate only towards one another, they have nothing elſe to fall to; and therefore have no occaſion for any thing to ſupport their common center of gravity; and if they did not move round that center, and conſequently acquire a tendency to fly off from it by their motions, their mutual attractions would ſoon bring them together; and ſo the whole would become one maſs in the ſun: which would alſo be the caſe if their velocities round the ſun were not quick enough to create a centrifugal force equal to the ſun's attraction.

But after all this nice adjuſtment, it appears evident that the Deity cannot withdraw his regulating hand from his works, and leave them to be ſolely governed by the laws which he has impreſt upon them at firſt. For if he ſhould once leave them ſo, their order would in time come to an end; becauſe the planets muſt neceſſarily diſturb one another's motions by their mutual attractions, when ſeveral of them are in the ſame quarter of the heavens; as is often the caſe: and then, as they attract the ſun more towards that quarter than when they are in a manner diſperſed equably around him, if he was not at that time made to deſcribe a portion of a larger circle round the common center of gravity, the balance would then be immediately deſtroyed; and as it could never reſtore itſelf again, the whole ſyſtem would begin to fall together, and would in time unite in a maſs at the ſun.— Of this diſturbance we have a very remarkable inſtance in the comet which appeared lately; and which, in going laſt up before from the ſun, went ſo near to Jupiter, and was ſo affected by his attraction,

attraction, as to have the figure of its orbit much changed; and not only so, but to have its period altered, and its course to be different in the heavens from what it was last before.

11. Take away the fork and balls from the whirling-board, and place the trough *AB* thereon, fixing its center to the center of the whirling-board by the pin *H*. In this trough are two balls *D* and *E*, of unequal weights, connected by a wire *f*; and made to slide easily upon the wire *C* stretched from end to end of the trough, and made fast by nut-screws on the outside of the ends. Let these balls be so placed upon the wire *C*, that their common center of gravity *g* may be directly over the center of the whirling-board. Then, turn the machine by the winch, ever so swiftly, and the trough and balls will go round their center of gravity, so as neither of them will fly off; because, on account of the equilibrium, each ball detains the other with an equal force acting against it. But if the ball *E* be drawn a little more towards the end of the trough at *A*, it will remove the center of gravity towards that end from the center of motion; and then, upon turning the machine, the little ball *E* will fly off, and strike with a considerable force against the end *A*, and draw the great ball *B* into the middle of the trough. Or, if the great ball *D* be drawn towards the end *B* of the trough, so that the center of gravity may be a little towards that end from the center of motion, and the machine be turned by the winch, the great ball *D* will fly off, and strike violently against the end *B* of the trough, and will bring the little ball *E* into the middle of it. If the trough be not made very strong, the ball *D* will break through it. Fig. 7.

12. The

Of the tides.

12. The reason why the tides rise at the same absolute time on opposite sides of the earth, and consequently in opposite directions, is made abundantly plain by a new experiment on the whirling-table. The cause of their rising on the side next the moon every one understands to be owing to the moon's attraction: but why they should rise on the opposite side at the same time, where there is no moon to attract them, is perhaps not so generally understood. For it would seem that the moon should rather draw the waters (as it were) closer to that side, than raise them upon it, directly contrary to her attractive force. Let the circle *a b c d* represent the earth, with its side *c* turned toward the moon, which will then attract the waters so, as to raise them from *c* to *g*. But the question is, why should they rise as high at that very time on the opposite side, from *a* to *e*? In order to explain this, let there be a plate *AB* fixed upon one end of the flat bar *DC*; with such a circle drawn upon it as *abcd* (in Fig. 8.) to represent the round figure of the earth and sea; and such an ellipsis as *efgh* to represent the swelling of the tide at *e* and *g*, occasioned by the influence of the moon. Over this plate *AB* let the three ivory balls *e*, *f*, *g*, be hung by the silk lines *h*, *i*, *k*, fastened to the tops of the crooked wires *H*, *I*, *K*, in such a manner, that the ball at *e* may hang freely over the side of the circle *e*, which is farthest from the moon, *M* (at the other end of the bar;) the ball at *f* may hang freely over the center, and the ball at *g* hang over the side of the circle *g*, which is nearest the moon. The ball *f* may represent the center of the earth, the ball *g* some water on the side next the moon, and the ball *e* some water on the opposite side. On the back of the moon *M* is fixt the short bar *N* pa-

Fig. 8.

Fig. 9.

N parallel to the horizon, and there are three holes in it above the little weights *p*, *q*, *r*. A ſilk thread *o* is tied to the line *k* cloſe above the ball *g*, and paſſing by one ſide of the moon *M*, goes through a hole in the bar *N*, and has the weight *p* hung to it. Such another thread *n* is tied to the line *i*, cloſe above the ball *f*, and paſſing through the center of the moon *M* and middle of the bar *N*, has the weight *q* hung to it, which is lighter than the weight *p*. A third thread *m* is tied to the line *h*, cloſe above the ball *e*, and paſſing by the other ſide of the moon *M*, through the bar *N*, has the weight *r* hung to it, which is lighter than the weight *q*.

The uſe of theſe three unequal weights is to repreſent the moon's unequal attraction at different diſtances from her. With whatever force ſhe attracts the center of the earth, ſhe attracts the ſide next her with a greater degree of force, and the ſide fartheſt from her with a leſs. So, if the weights are left at liberty, they will draw all the three balls towards the moon with different degrees of force, and cauſe them to make the appearance ſhewn in Fig. 10; by which means they are evidently farther from each other than they would be if they hung at liberty by the lines *h*, *i*, *k*; becauſe the lines would then hang perpendicularly. This ſhews, that as the moon attracts the ſide of the earth which is neareſt her with a greater degree of force than ſhe does the center of the earth, ſhe will draw the water on that ſide more than ſhe draws the center, and ſo cauſe it to riſe on that ſide: and as ſhe draws the center more than ſhe draws the oppoſite ſide, the center will recede farther from the ſurface of the water to that oppoſite ſide, and ſo leave it as high there as ſhe raiſed it on the ſide next to her. Fig. 10.

For,

For, as the center will be in the middle between the tops of the opposite elevations, they must of course be equally high on both sides at the same time.

But upon this supposition the earth and moon would soon come together: and to be sure they would, if they had not a motion round their common center of gravity, to create a degree of centrifugal force sufficient to balance their mutual attraction. This motion they have; for as the moon goes round her orbit every month, at the distance of 240000 miles from the earth's center, and of 234000 miles from the center of gravity of the earth and moon, so does the earth go round the same center of gravity every month at the distance of 6000 miles from it; that is, from it to the center of the earth. Now as the earth is (in round numbers) 8000 miles in diameter, it is plain that its side next the moon is only 2000 miles from the common center of gravity of the earth and moon; its center 6000 miles distant therefrom; and its farther side from the moon 10000. Therefore the centrifugal forces of these parts are as 2000, 6000, and 10000; that is, the centrifugal force of any side of the earth, when it is turned from the moon, is five times as great as when it is turned towards the moon. And as the moon's attraction (exprest by the number 6000) at the earth's center keeps the earth from flying out of this monthly circle, it must be greater than the centrifugal force of the waters on the side next her; and consequently, her greater degree of attraction on that side is sufficient to raise them; but as her attraction on the opposite side is less than the centrifugal force of the water there, the excess of this force is sufficient to raise the water just as high

high on the opposite side.—To prove this experimentally, let the bar *DC* with its furniture be fixed upon the whirling-board of the machine (Fig. 1.) by pushing the pin *P* into the center of the board; which pin is in the center of gravity of the whole bar with its three balls *e*, *f*, *g*, and moon *M*. Now if the whirling-board and bar be turned slowly round by the winch, until the ball *f* hangs over the center of the circle, as in Fig. 11. the ball *g* will be kept towards the moon by the heaviest weight *p*, (Fig. 9.) and the ball *e*, on account of its greater centrifugal force, and the lesser weight *r*, will fly off as far to the other side, as in Fig. 11. And so, whilst the machine is kept turning, the balls *e* and *g* will hang over the ends of the ellipsis *l f k*. So that the centrifugal force of the ball *e* will exceed the moon's attraction just as much as her attraction exceeds the centrifugal force of the ball *g*, whilst her attraction just balances the centrifugal force of the ball *f*, and makes it keep in its circle. And hence it is evident that the tides must rise to equal heights at the same time on opposite sides of the earth. This experiment, to the best of my knowledge, is entirely new. Fig. 9.

The earth's motion demonstrated.

From the principles thus established, it is evident that the earth moves round the sun, and not the sun round the earth: for the centrifugal law will never allow a great body to move round a small one in any orbit whatever; especially when we find that if a small body moves round a great one, the great one must also move round the common center of gravity between them two. And it is well known that the quantity of matter in the sun is 227000 times as great as the quantity of matter in the earth. Now, as the sun's

distance

diſtance from the earth is at leaſt 81,000,000 of miles, if we divide that diſtance by 227000, we ſhall have only 357 for the number of miles that the center of gravity between the ſun and earth is diſtant from the ſun's center. And as the ſun's ſemidiameter is $\frac{1}{4}$ of a degree, which, at ſo great a diſtance as that of the ſun, muſt be no leſs than 381500 miles, if this be divided by 357, the quotient will be 1068 $\frac{2}{3}$, which ſhews that the common center of gravity is within the body of the ſun; and is only the 1068$\frac{2}{3}$ part of his ſemidiameter from his center toward his ſurface.

All globular bodies, whoſe parts can yield, and which do not turn on their axes, muſt be perfect ſpheres, becauſe all parts of their ſurfaces are equally attracted toward their centers. But all ſuch globes which do turn on their axes will be oblate ſpheroids; that is, their ſurfaces will be higher, or farther from the center, in the equatoreal than in the polar regions. For, as the equatoreal parts move quickeſt, they muſt have the greateſt centrifugal force; and will therefore recede fartheſt from the axis of motion. Thus, if two circular hoops *AB* and *CD*, made thin and flexible, and croſſing one another at right angles, be turned round their axis *EF* by means of the winch *m*, the wheel *n*, and pinion *o*, and the axis be looſe in the pole or interſection *e*, the middle parts *A*, *B*, *C*, *D* will ſwell out ſo as to ſtrike againſt the ſides of the frame at *F* and *G*, if the pole *e*, in ſinking to the pin *E*, be not ſtopt by it from ſinking farther: ſo that the whole will appear of an oval figure, the equatoreal diameter being conſiderably longer than the polar. That our earth is of this figure, is demonſtrable from actual mea-

Fig. 12.

ſurement of ſome degrees on its ſurface, which are found to be longer in the frigid zones than in the torrid: and the difference is found to be ſuch as proves the earth's equatoreal diameter to be 35 miles longer than its axis.—Since then, the earth is higher at the equator than at the poles, the ſea, which like all other fluids naturally runs downward (or towards the places which are neareſt the earth's center) would run towards the polar regions, and leave the equatoreal parts dry, if the centrifugal force of the water, which carried it to thoſe parts, and ſo raiſed them, did not detain and keep it from running back again towards the poles of the earth.

LECT. III.

Of the mechanical powers.

IF we conſider bodies in motion, and compare them together, we may do this either with reſpect to the quantities of matter they contain, or the velocities with which they are moved. The heavier any body is, the greater is the power required either to move it or to ſtop its motion: and again, the ſwifter it moves, the greater is its force. So that the whole *momentum* or quantity of force of a moving body is the reſult of its quantity of matter multiplied by the velocity with which it is moved. And when the products ariſing from the multiplication of the particular quantities of matter in any two bodies by their reſpective velocities are equal, the *momenta* or entire forces are ſo too. Thus, ſuppoſe a body, which we ſhall call *A*, to weigh 40 pounds, and to move at the rate of two miles in

The foundation of all mechanics.

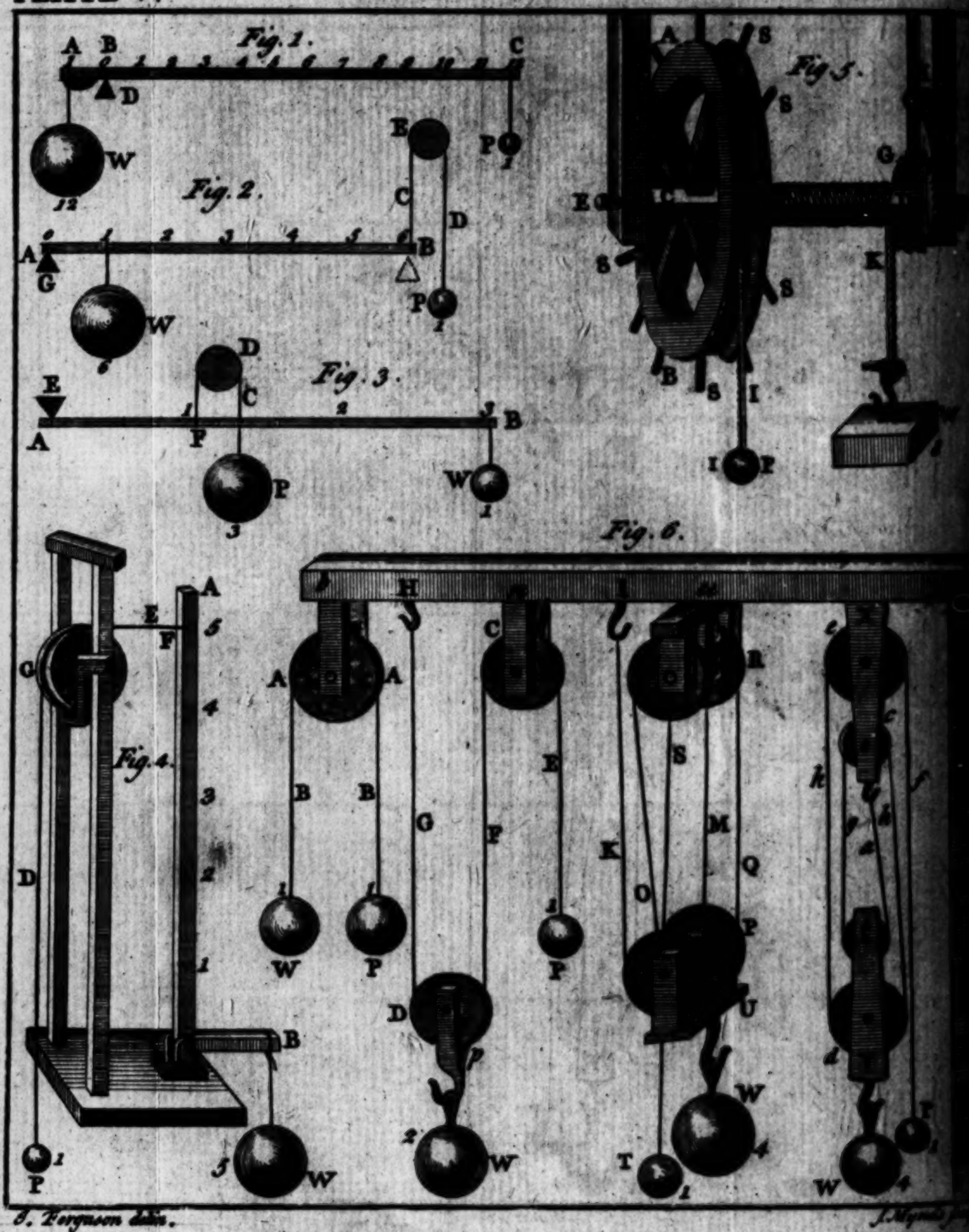
in a minute; and another body, which we shall call *B*, to weigh only four pounds, and to move 20 miles in a minute; the entire forces with which these two bodies would strike against any obstacle would be equal to each other, and therefore it would require equal powers to stop them. For 40 multiplied by 2 gives 80, the force of the body *A*; and 20 multiplied by 4 gives 80, the force of the body *B*.

Upon this easy principle depends the whole of mechanics: and it holds universally true, that when two bodies are suspended by any machine, so as to act contrary to each other; if the machine be put into motion, and the perpendicular ascent of one body multiplied into its weight, be equal to the perpendicular descent of the other body multiplied into its weight, these bodies, how unequal soever in their weights, will balance one another in all situations: for, as the whole ascent of one is performed in the same time with the whole descent of the other, their respective velocities must be directly as the spaces they move through; and the excess of weight in one body is compensated by the excess of velocity in the other.—Upon this principle it is easy to compute the power of any mechanical engine, whether simple or compound; for it is but only enquiring how much swifter the power moves than the weight does (*i. e.* how much farther in the same time) and just so much is the power increased by the help of the engine.

How to compute the power of any mechanical engine.

In the theory of this science, we suppose all planes perfectly even, all bodies perfectly smooth, levers to have no weight, cords to be extremely pliable, machines to have no friction; and in short, all imperfections must be set aside until the

PLATE V.



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the theory be eſtabliſhed; and then, proper allowances are to be made.

The ſimple *machines*, uſually called *mechanical powers*, are ſix in number, viz. the *lever*, the *wheel and axle*, the *pulley*, the *inclined plane*, the *wedge*, and the *ſcrew*.—They are called mechanical powers, becauſe they help us to raiſe weights, move heavy bodies, and overcome reſiſtances, which we could not effect without them. The mechanic powers, what.

1. A *lever* is a bar of iron or wood, one part of which being ſupported by a prop, all the other parts turn upon that prop as their center of motion: and the velocity of every part or point is directly as its diſtance from the prop. Therefore, when the weight to be raiſed at one end is to the power applied at the other to raiſe it, as the diſtance of the power from the prop is to the diſtance of the weight from the prop, the power and weight will exactly balance or counterpoiſe each other: and as a common lever has but very little friction on its prop, a very little additional power will be ſufficient to raiſe the weight. The *lever*.

There are four kinds of levers. 1. The common ſort, where the prop is placed between the weight and the power; but much nearer to the weight than the power. 2. When the prop is at one end of the lever, the power at the other, and the weight between them. 3. When the prop is at one end, the weight at the other, and the power applied between them. 4. The bended lever, which differs only in form from the firſt ſort, but not in property. Thoſe of the firſt and ſecond kind are often uſed in mechanical engines; but there are few inſtances in which the third ſort is uſed.

The *balance.*

A *common balance* is a lever of the firſt kind; but as both its ends are at equal diſtances from its center of motion, they move with equal velocities; and therefore, as it gives no mechanical advantage, it cannot properly be reckoned among the mechanical powers.

Plate V. Fig. 1. The firſt kind of lever.

A lever of the firſt kind is repreſented by the bar *ABC*, ſupported by the prop *D*. Its principal uſe is to looſen large ſtones in the ground, or raiſe great weights to ſmall heights, in order to have ropes put under them for raiſing them higher by other machines. The parts *AB* and *BC*, on different ſides of the prop *D*, are called the *arms* of the lever: the end *A* of the ſhorter arm *A B* being applied to the weight intended to be raiſed, or to the reſiſtance to be overcome; and the power applied to the end *C* of the longer arm *B C*.

In making experiments with this machine, the ſhorter arm *A B* muſt be as much thicker than the longer arm *B C*, as will be ſufficient to balance it on the prop. This ſuppoſed, let *P* repreſent a power, whoſe intenſity is equal to 1 ounce, and *W* a weight, whoſe intenſity is equal to 12 ounces. Then, if the power be 12 times as far from the prop as the weight is, they will exactly counterpoiſe; and a ſmall addition to the power *P* will cauſe it to deſcend, and raiſe the weight *W*; and the velocity with which the power deſcends will be to the velocity with which the weight riſes, as 12 to 1: that is, directly as their diſtances from the prop; and conſequently, as the ſpaces through which they move. Hence, it is plain that a man who by his natural ſtrength, without the help of any machine, could ſupport an hundred weight, will by the help of this lever be enabled to ſupport

twelve

twelve hundred. If the weight be leſs, or the power greater, the prop may be placed ſo much farther from the weight; and then it can be raiſed to a proportionably greater height. For univerſally, if the intenſity of the weight multiplied into its diſtance from the prop be equal to the intenſity of the power multiplied into its diſtance from the prop, the power and weight will exactly balance each other; and a little addition to the power will raiſe the weight. Thus, in the preſent inſtance, the weight *W* is 12 ounces, and its diſtance from the prop is 1 inch; and 12 multiplied by 1 is 12; the power *P* is equal to 1 ounce, and its diſtance from the prop is 12 inches, which multiplied by 1 is 12 again; and therefore there is an equilibrium between them. So, if a power equal to 2 ounces be applied at the diſtance of 6 inches from the prop, it will juſt balance the weight *W*; for 6 multiplied by 2 is 12, as before. And a power equal to 3 ounces placed at 4 inches diſtance from the prop would be the ſame; for 3 times 4 is 12; and ſo on, in proportion.

The *ſtatera* or Roman *ſteelyard* is a lever of this kind, contrived for finding the weights of different bodies by one ſingle weight placed at different diſtances from the prop or center of motion *D*. For, if a ſcale hangs at *A*, the extremity of the ſhorter arm *A B*, and is of ſuch a weight as will exactly counterpoiſe the longer arm *BC*; if this arm be divided into as many equal parts as it will contain, each equal to *A B*, the ſingle weight *P* (which we may ſuppoſe to be 1 pound) will ſerve for weighing any thing as heavy as itſelf, or as many times heavier as there are diviſions in the arm *B C*, or any quantity between its own weight and that quantity. The *ſteel-yard.*

As for example, if *P* be 1 pound, and placed at the first division 1 in the arm *BC*, it will balance 1 pound in the scale at *A*: if it be removed to the second division at 2, it will balance 2 pounds in the scale: if to the third, 3 pounds; and so on to the end of the arm *BC*. If each of these integral divisions be subdivided into as many equal parts as a pound contains ounces, and the weight *P* be placed at any of these subdivisions, so as to counterpoise what is in the scale, the pounds and odd ounces therein are by that means ascertained.

To this kind of lever may be reduced several sorts of instruments, such as scissars, pinchers, snuffers; which are made of two levers acting contrary to one another: their prop or center of motion being the pin which keeps them together.

In common practice, the longer arm of this lever greatly exceeds the weight of the shorter; which gains great advantage, because it adds so much to the power.

The second kind of lever.

A lever of the second kind has the weight between the prop and the power. In this, as well as the former, the advantage gained is as the distance of the power from the prop to the distance of the weight from the prop: for the respective velocities of the power and weight are in that proportion; and they will balance each other when the intensity of the power multiplied by its distance from the prop is equal to the intensity of the weight multiplied by its distance from the prop. Thus, if *AB* be a lever on which the weight *W* of 6 ounces hangs at the distance of 1 inch from the prop *G*, and a power *P* equal to the weight of 1 ounce hangs at the end *B*, 6 inches from the prop, by the cord *CD*

Fig. 2.

CD going over the fixed pulley *E*, the power will juſt ſupport the weight: and a ſmall addition to the power will raiſe the weight, 1 inch for every 6 inches that the power deſcends.

This lever ſhews the reaſon why two men carrying a burden upon a ſtick between them, bear unequal ſhares of the burden in the inverſe proportion of their diſtances from it. For it is well known, that the nearer any of them is to the burden, the greater ſhare he bears of it: and if he goes directly under it, he bears the whole. So, if one man be at *G*, and the other at *P*, having the pole or ſtick *AB* reſting on their ſhoulders; if the burden or weight *W* be placed five times as near the man at *G*, as it is to the man at *P*, the former will bear five times as much weight as the latter. This is likewiſe applicable to the caſe of two horſes of unequal ſtrength, to be ſo yoked, as that each horſe may draw a part proportionable to his ſtrength; which is done by dividing the beam ſo, that the point of traction may be as much nearer to the ſtronger horſe than to the weaker, as the ſtrength of the former exceeds that of the latter.

To this kind of lever may be reduced oars, rudders of ſhips, doors turning upon hinges, cutting-knives which are fixed at the point of the blade, and the like.

The third kind of lever.

If in this lever we ſuppoſe the power and weight to change places, ſo that the power may be between the weight and the prop, it will become a lever of the third kind: in which, that there may be a balance between the power and the weight, the intenſity of the power muſt exceed the intenſity of the weight, juſt as much as the diſtance of the weight from the prop ex-

ceeds the distance of the power from it. Thus, let *E* be the prop of the lever *AB*, and *W* a weight of 1 pound, placed 3 times as far from the prop, as the power *P* acts at *F*, by the cord *C* going over the fixed pulley *D*; in this case, the power must be equal to three pounds, in order to support the weight.

Fig. 3.

To this sort of lever are generally referred the bones of a man's arm: for when we lift a weight by the hand, the muscle that exerts its force to raise that weight, is fixed to the bone about one tenth part as far below the elbow as the hand is. And the elbow being the center round which the lower part of the arm turns, the muscle must therefore exert a force ten times as great as the weight that is raised.

As this kind of lever is a disadvantage to the moving power, it is never used but in cases of necessity; such as that of a ladder, which being fixed at one end, is by the strength of a man's arms reared against a wall. And in clock-work, where all the wheels may be reckoned levers of this kind, because the power that moves every wheel, except the first, acts upon it near the center of motion by means of a small pinion, and the resistance it has to overcome, acts against the teeth round its circumference.

The fourth kind of lever. Fig. 4.

The fourth kind of lever differs nothing from the first, but in being bended for the sake of convenience. *ABC* is a lever of this sort, bended at *C*, which is its prop, or center of motion. *P* is a power acting upon the longer arm *AC* at *F*, by means of the cord *DE* going over the pully *G*; and *W* is a weight or resistance acting upon the end *B* of the shorter arm *BC*. If the power be to the weight, as *BC* is to *CF*, they are in *equilibrio*. Thus, suppose *W* to be 5

pounds

pounds acting at the diſtance of one foot from the center of motion *C*, and *P* to be 1 pound acting at *F*, five feet from the center *C*, the power and weight will juſt balance each other. A hammer drawing a nail is a lever of this ſort.

2. The ſecond mechanical power is the *wheel and axle*, in which the power is applied to the circumference of the wheel, and the weight is raiſed by a rope which coils about the axle as the wheel is turned round. Here it is plain that the velocity of the power muſt be to the velocity of the weight, as the circumference of the wheel is to the circumference of the axle: and conſequently, the power and weight will balance each other, when the intenſity of the power is to the intenſity of the weight, as the circumference of the axle is to the circumference of the wheel. Let *AB* be a wheel, *CD* its axle, and ſuppoſe the circumference of the wheel to be 8 times as great as the circumference of the axle; then, a power *P* equal to 1 pound hanging by the cord *I*, which goes round the wheel, will balance a weight *W* of 8 pounds hanging by the rope *K*, which goes round the axle. And as the friction on the pivots or gudgeons of the axle is but ſmall, a ſmall addition to the power will cauſe it to deſcend, and raiſe the weight: but the weight will riſe with only an eighth part of the velocity wherewith the power deſcends, and conſequently, through no more than an eighth part of an equal ſpace, in the ſame time. If the wheel be pulled round by the handles *S*, *S*, the power will be increaſed in proportion to their length. And by this means, any weight may be raiſed as high as the operator pleaſes.

The *wheel and axle.*

Fig. 5.

To this ſort of engine belong all cranes for raiſing great weights; and in this caſe, the wheel may have cogs all round it inſtead of handles, and a ſmall lantern or trundle may be made to work in the cogs, and be turned by a winch; which will make the power of the engine to exceed the power of the man who works it, as much as the number of revolutions of the winch exceed thoſe of the axle *D*, when multiplied by the exceſs of the length of the winch above the length of the ſemidiameter of the axle, added to the ſemidiameter or half thickneſs of the rope *K*, by which the weight is drawn up.—Thus, ſuppoſe the diameter of the rope and axle taken together, to be 12 inches, and conſequently, half their diameters to be 6 inches; ſo that the weight *W* will hang at 6 inches perpendicular diſtance from below the center of the axle. Now, let us ſuppoſe the wheel *AB*, which is fixt on the axle, to have 80 cogs, and to be turned by means of a winch ſix inches long, fixt on the axis of a trundle of 8 ſtaves or rounds, working in the cogs of the wheel.—Here it is plain, that the winch and trundle would make 10 revolutions for one of the wheel *AB*, and its axis *D*, on which the rope *K* winds in raiſing the weight *W*; and the winch being no longer than the ſum of the ſemidiameters of the great axle and rope, the trundle could have no more power on the wheel, than a man could have by pulling it round by the edge, becauſe the winch would have no greater velocity than the edge of the wheel has, which we here ſuppoſe to be ten times as great as the velocity of the riſing weight: ſo that, in this caſe, the power gained would be as 10 to 1. But if the length of the winch be 12 inches, the power gained

gained will be as 20 to 1: if 18 inches (which is long enough for any man to work by) the power gained would be as 30 to 1; that is, a man could raiſe 30 times as much by ſuch an engine, as he could do by his natural ſtrength without it, becauſe the velocity of the handle of the winch would be 30 times as great as the velocity of the riſing weight; the abſolute force of any engine being in proportion of the velocity of the power to the velocity of the weight raiſed by it.—But then, juſt as much power or advantage as is gained by the engine, ſo much time is loſt in working it. In this ſort of machines it is requiſite to have a racket-wheel *G* on one end of the axle, with a catch *H* to fall into its teeth; which will at any time ſupport the weight, and keep it from deſcending, if the workman ſhould, through inadvertency or careleſneſs, quit his hold whilſt the weight is raiſing. And by this means, the danger is prevented which might otherwiſe happen by the running down of the weight when left at liberty.

3. The third mechanical power or engine conſiſts either of one *moveable pulley*, or a *ſyſtem of pulleys*; ſome in a block or caſe which is fixed, and others in a block which is moveable, and riſes with the weight. For though a ſingle pulley that only turns on its axis, and riſes not without the weight, may ſerve to change the direction of the power, yet it can give no mechanical advantage thereto; but is only as the beam of a balance, whoſe arms are of equal length and weight. Thus, if the equal weights *W* and *P* hang by the cord *BB* upon the pulley *A*, whoſe block *b* is fixed to the beam *HI*, they will counterpoiſe each other, juſt in the ſame manner as if the cord were cut in the middle, and its two ends

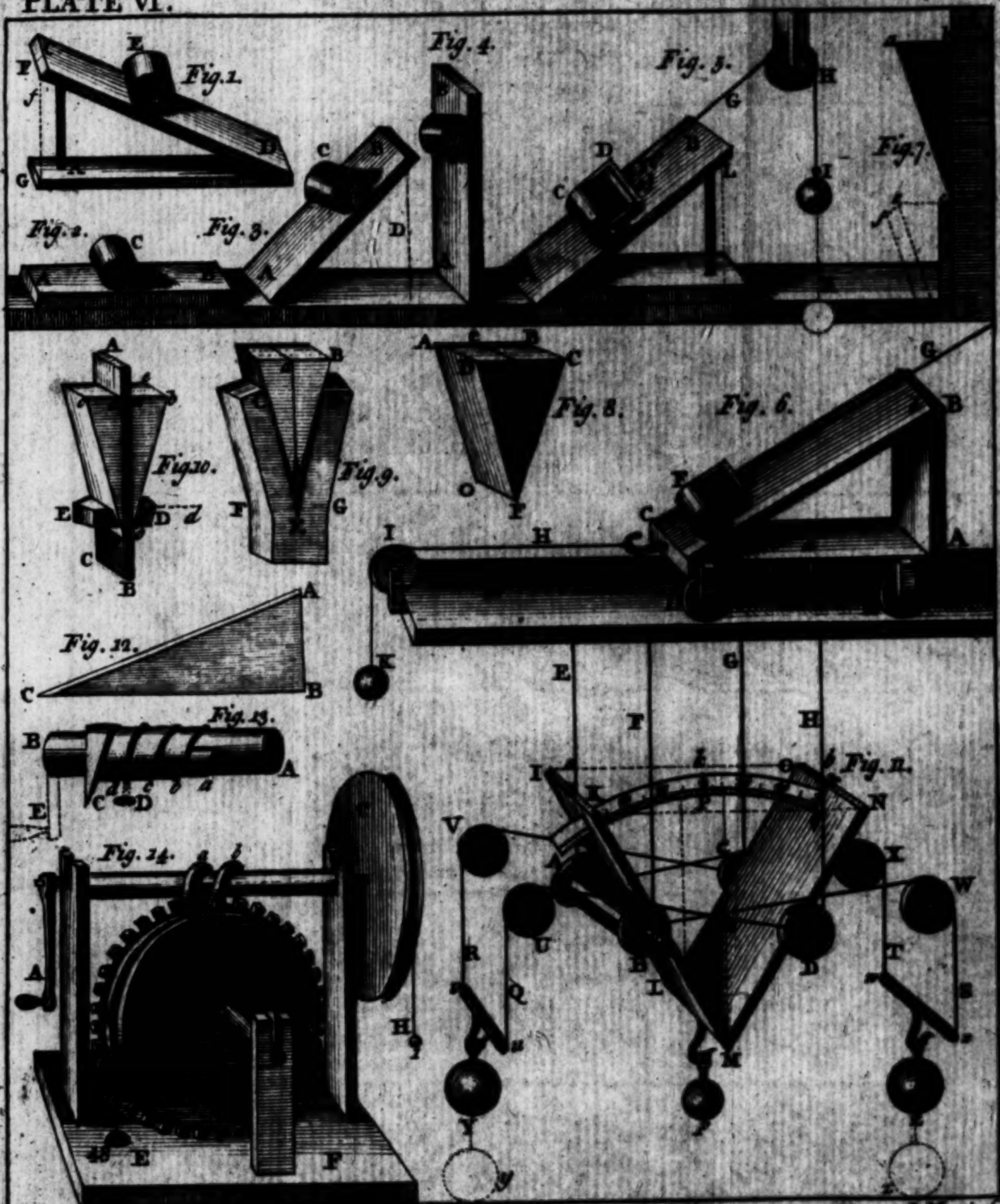
The *pulley*.

Fig. 6.

ends hung upon the hooks fixt in the pulley at *A* and *A*, equally distant from its center.

But if a weight *W* hangs at the lower end of the moveable block *p* of the pulley *D*, and the cord *G F* goes under the pulley, it is plain that the half *G* of the cord bears one half of the weight *W*, and the half *F* the other; for they bear the whole between them. Therefore, whatever holds the upper end of either rope, sustains one half of the weight: and if the cord at *F* be drawn up so as to raise the pulley *D* to *C*, the cord will then be extended to its whole length, all but that part which goes under the pulley; and consequently, the power that draws the cord will have moved twice as far as the pulley *D* with its weight *W* rises; on which account, a power whose intensity is equal to one half of the weight will be able to support it, because if the power moves (by means of a small addition) its velocity will be double the velocity of the weight; as may be seen by putting the cord over the fixt pulley *C* (which only changes the direction of the power, without giving any advantage to it) and hanging on the weight *P*, which is equal only to one half of the weight *W*; in which case there will be an equilibrium, and a little addition to *P* will cause it to descend, and raise *W* through a space equal to one half of that through which *P* descends.—Hence, the advantage gained will be always equal to twice the number of pulleys in the moveable or undermost block. So that, when the upper or fixt block *u* contains two pulleys, which only turn on their axes, and the lower or moveable block *U* contains two pulleys, which not only turn upon their axes, but also rise with the block and weight; the advantage gained by this is as 4 to the working

PLATE VI.



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orking power. Thus, if one end of the rope *MOQ* be fixed to a hook at *I*, and the rope asses over the pulleys *N* and *R*, and under the ulleys *L* and *P*, and has a weight *T*, of one ound, hung to its other end at *T*, this weight ill balance and ſupport a weight *W* of four ounds hanging by a hook at the moveable lock *U*, allowing the ſaid block as a part of the eight. And if as much more power be added, s is ſufficient to overcome the friction of the ulleys, the power will deſcend with four times s much velocity as the weight riſes, and conſe- uently through four times as much ſpace.

The two pulleys in the fixed block *X*, and the wo in the moveable block *Y*, are in the ſame aſe with thoſe laſt mentioned; and thoſe in the ower block give the ſame advantage to the ower.

As a ſyſtem of pulleys has no great weight, nd lies in a ſmall compaſs, it is eaſily carried bout; and can be applied, in a great many aſes, for raiſing weights, where other engines annot. But they have a great deal of friction n three accounts: 1. becauſe the diameters of heir axes bear a very conſiderable proportion to heir own diameters; 2. becauſe in working hey are apt to rub againſt one another, or againſt he ſides of the block; 3. becauſe of the ſtiffneſs f the rope that goes over and under them.

4. The fourth mechanical power is the *in- lined plane*; and the advantage gained by it is great as its length exceeds its perpendicular eight. Let *AB* be a plane parallel to the hori- on, and *CD* a plane inclined to it; and ſuppoſe e whole length *CD* to be three times as great the perpendicular height *GfF*: in this caſe, e cylinder *E* will be ſupported upon the plane *CD*,

The *in- clined plane.*

Plate VI. Fig. 1.

CD, and kept from rolling down upon it, by a power equal to a third part of the weight of the cylinder. Therefore, a weight may be rolled up this inclined plane with a third part of the power which would be ſufficient to draw it up by the ſide of an upright wall. If the plane was four times as long as high, a fourth part of the power would be ſufficient; and ſo on, in proportion. Or, if a pillar was to be raiſed from a floor to the height GF, by means of the engine $ABDC$, (which would then act as a half wedge, where the reſiſtance gives way only on one ſide) the engine and pillar would be in *equilibrio* when the power applied at GF was to the weight of the pillar, as GF to GD; and if the power be increaſed, ſo as to overcome the friction of the engine againſt the floor and pillar, the engine will be driven, and the pillar raiſed: and when the engine has moved its whole length upon the floor, the pillar will be raiſed to the whole height of the engine, from G to F.

The force wherewith a rolling body deſcends upon an inclined plane, is to the force of its abſolute gravity, by which it would deſcend perpendicularly in a free ſpace, as the height of the plane is to its length. For, ſuppoſe the plane
Fig. 2. AB to be parallel to the horizon, the cylinder C will keep at reſt upon any part of the plane where it is laid. If the plane be ſo elevated,
Fig. 3. that its perpendicular height D is equal to half its length AB, the cylinder will roll down upon the plane with a force equal to half its weight; for it would require a power (acting on the direction of AB) equal to half its weight, to keep
Fig. 4. it from rolling. If the plane AB be elevated ſo as to be perpendicular to the horizon, the cylinder C will deſcend with its whole force of gravity

gravity, becauſe the plane contributes nothing to its ſupport or hindrance; and therefore, it would require a power equal to its whole weight to keep it from deſcending.

Let the cylinder *C* be made to turn upon ſlender pivots in the frame *D*, in which there is a hook *e*, with a line *G* tied to it: let this line go over the fixed pulley *H*, and have its other end tied to the hook in the weight *I*. If the weight of the body *I*, be to the weight of the cylinder *C*, added to that of its frame *D*, as the perpendicular height of the plane *LM* is to its length *AB*, the weight will juſt ſupport the cylinder upon the plane, and a ſmall touch of a finger will either cauſe it to aſcend or deſcend with equal eaſe: then, if a little addition be made to the weight *I*, it will deſcend, and draw the cylinder up the plane. In the time that the cylinder moves from *A* to *B*, it will riſe through the whole height of the plane *ML*; and the weight will deſcend from *H* to *K*, through a ſpace equal to the whole length of the plane *AB*. Fig. 5.

If the plane be made to move upon rollers or friction-wheels, and the cylinder be ſupported upon it; the ſame power will draw the plane under the cylinder, which before drew the cylinder up the plane, provided the pivots of the axes of the friction-wheels be ſmall, and the wheels themſelves be pretty large. For, let the machine *ABC* (equal in length and height to *ABM*, Fig. 5.) be provided with four wheels, whereof two appear at *D* and *E*, and the third under *C*, whilſt the fourth is hid from ſight by the horizontal board *a*. Let the cylinder *F* be laid upon the lower end of the inclined plane *CB*, and the line *G* be extended from the frame of the cylinder, about ſix feet parallel to the plane Fig. 6.

plane CB; and, in that direction, fixed to a hook in the wall; which will support the cylinder, and keep it from rolling off the plane. Let one end of the line H be tied to a hook at C in the machine, and the other end to a weight K, the same as drew the cylinder up the plane before. If this line be put over the fixed pulley I, the weight K will draw the machine along the horizontal plane L, and under the cylinder F; and when the machine has been drawn the whole length CB, the cylinder will be raised to A, equal to the perpendicular height AB above the horizontal part at A.

To the inclined plane may be reduced all hatchets, chisels, and other edge-tools which are chamfered only on one side.

The *wedge*.

Fig. 8.

5. The fifth mechanical power or engine is the *wedge*, which may be considered as two equally inclined planes DEF and CEF, joined together at their bases eEF: then, DC is the whole thickness of the wedge at its back $ABCD$, where the power is applied: EF is the depth or heighth of the wedge: DF the length of one of its sides, equal to CF the length of the other side; and OF is its sharp edge, which is entered into the wood intended to be split by the force of a hammer or mallet striking perpendicularly on its back. Thus, ABb is a wedge driven into the cleft CDE of the wood FG.

Fig. 9.

When the wood does not cleave at any distance before the wedge, there will be an equilibrium between the power impelling the wedge downward, and the resistance of the wood acting against the two sides of the wedge; if the power be to the resistance, as half the thickness of the wedge at its back is to the length of either of its sides; that is, as Aa to Ab, or Ba to Bb

‡ (Fig. 9.)

(Fig. 9.) And if the power be increaſed, ſo as to overcome the friction of the wedge and the reſiſtance ariſing from the coheſion or ſtickage of the wood, the wedge will be drove in, and the wood ſplit aſunder.

But, when the wood cleaves at any diſtance before the wedge (as it generally does) the power impelling the wedge will not be to the reſiſtance of the wood, as half the thickneſs of the wedge is to the length of one of its ſides; but as half its thickneſs is to the length of either ſide of the cleft, eſtimated from the top or acting part of the wedge. For, if we ſuppoſe the wedge to be lengthened down from *b* to the bottom of the cleft at *E*, the ſame proportion will hold; namely, that the power will be to the reſiſtance, as half the thickneſs of the wedge is to the length of either of its ſides: or, which amounts to the ſame thing, as the whole thickneſs of the wedge is to the length of both its ſides.

In order to prove what is here advanced concerning the wedge, let us ſuppoſe the wedge to be divided lengthwiſe into two equal parts; and then it will become two equally inclined planes; one of which, as *a b c*, may be made uſe of as a half wedge for ſeparating the moulding *c d* from the wainſcot *A B*. It is evident, that when this half wedge has been driven its whole length *a c* between the wainſcot and moulding, its ſide *a c* will be at *e d*; and the moulding will be ſeparated to *f g* from the wainſcot. Now, from what has been already proved of the inclined plane, it appears, that to have an equilibrium between the power impelling the half wedge, and the reſiſtance of the moulding, the former muſt be to the latter, as *a b* to *a c*; that is, as the thickneſs of the back which receives the ſtroke is to the length of the Fig. 7.

the

the side against which the moulding acts. Therefore, since the power upon the half wedge is to the resistance against its side, as the half back *ab* is to the whole side *ac*, it is plain, that the power upon which the whole wedge (where the whole back is double the half back) must be to the resistance against both its sides, as the thickness of the whole back is to the length of both the sides; supposing the wedge at the bottom of the cleft: or as the thickness of the whole back to the length of both sides of the cleft, when the wood splits at any distance before the wedge. For, when the wedge is driven quite into the wood, and the wood splits at ever so small a distance before its edge, the top of the wedge then becomes the acting part, because the wood does not touch it any where else. And since the bottom of the cleft must be considered as that part where the whole stickage or resistance is accumulated, it is plain, from the nature of the lever, that the farther the power acts from the resistance, the greater is the advantage.

Some writers have advanced, that the power of the wedge is to the resistance to be overcome, as the thickness of the back of the wedge is to the length only of one of its sides; which seems very strange: for, if we suppose *AB* to be a
Fig. 10. strong inflexible bar of wood or iron fixt into the ground at *CB*, and *D* and *E* to be two blocks of marble lying on the ground on opposite sides of the bar; it is evident that the block *D* may be separated from the bar to the distance *d*, equal to *ab*, by driving the inclined plane or half wedge *abo* down between them; and the block *E* may be separated to an equal distance on the other side, in like manner, by the half wedge *cdo*. But the power impelling each half wedge will be to

to the resistance of the block against its side, as the thickness of that half wedge is to the length of its acting side. Therefore the power to drive both the half wedges is to both the resistances, as both the half backs is to the length of both the acting sides, or as half the thickness of the whole back is to the length of either side. And if the bar be taken away, the blocks put close together, and the two half wedges joined to make one; it will require as much force to drive it down between the blocks, as is equal to the sum of the separate powers acting upon the half wedges when the bar was between them.

To confirm this by an experiment, let two cylinders, as *AB* and *CD*, be drawn towards one another by lines running over fixed pulleys, and a weight of 40 ounces hanging at the lines belonging to each cylinder: and let a wedge of 40 ounces weight, having its back just as thick as either of its sides is long, be put between the cylinders, which will then act against each side with a resistance equal to 40 ounces, whilst its own weight endeavours to bring it down and separate them. And here, the power of the wedge's gravity impelling it downward, will be to the resistance of both the cylinders against the wedge, as the thickness of the wedge is to the length of both its sides; for there will then be an equilibrium between the weight of the wedge and the resistance of the cylinders against it, and it will remain at any height between them; requiring just as much power to push it upward as to pull it downward.—If another wedge of equal weight and depth with this, and only half as thick, be put between the cylinders, it will require twice as much weight to be hung at the ends of the lines which draw them together, to Fig. 11.

F keep

keep the wedge from going down between them. That is, a wedge of 40 ounces, whose back is only equal to half the length of one of its sides, will require 80 ounces to each cylinder, to keep it in an equilibrium between them: and twice 80 is 160, equal to four times 40. So that the power will be always to the resistance, as the thickness of the back of the wedge is to the length (not of its one side, but) of both its sides.

The best way, though perhaps not the neatest, that I know of, for making a wedge with its appurtenances for such experiments, is as follows. Let *IKLM* and *LMNO* be two flat pieces of wood, each about fifteen inches long and three or four in breadth, joined together by a hinge at *LM*; and let *P* be a graduated arch of brass, on which the said pieces of wood may be opened to any angle not more than 60 degrees, and then fixt at the given angle by means of the two screws *a* and *b*. Then, *IKNO* will represent the back of the wedge *LM*, its sharp edge which enters the wood, and the outsides of the pieces *IKLM* and *LMNO* the two sides of the wedge against which the wood acts in cleaving. By means of the said arch, the wedge may be opened so, as to adjust the thickness of its back in any proportion to the length of either of its sides, but not to exceed that length: and any weight as *p* may be hung to the wedge upon the hook *M*, which weight, together with the weight of the wedge itself, may be considered as the impelling power; which is all the same in experiment, whether it be laid upon the back of the wedge, to push it down, or hung to its edge to pull it down.—Let *AB* and *CD* be two wooden cylinders, each about two inches thick, where they

Fig. 11.

they touch the outsides of the wedge; and let their ends be made like two round flat plates, to keep the wedge from slipping off endwise between them. Let a small cord with a loop on one end of it, go over a pivot in the end of each cylinder, and the cords *S* and *T* belonging to the cylinder *AB* go over the fixt pulleys *W* and *X*, and be fastened at their other ends to the bar *wx*, on which any weight as *Z* may be hung at pleasure. In like manner, let the cords *Q* and *R* belonging to the cylinder *BC* go over the fixt pulleys *U* and *V* to the bar *uv*, on which a weight *Y* equal to *Z* may be hung. These weights, by drawing the cylinders towards one another, may be considered as the resistance of the wood acting equally against opposite sides of the wedge; the cylinders themselves being suspended near, and parallel to each other, by their pivots in loops on the lines *E,F,G,H*; which lines may be fixed to hooks in the ceiling of the room. The longer these lines are, the better; and they should never be less than four feet each. The farther also the pulleys *W,V* and *W,X* are from the cylinders, the truer will the experiments be: and they may turn upon pins fixed into the wall.

In this machine, the weights *Y* and *Z*, and the weight *p*, may be varried at pleasure, so as to be adjusted in proportion of the length of the wedge's sides to the thickness of its back; and when they are so adjusted, the wedge will be in *equilibrio* with the resistance of the cylinders.

The wedge is a very great mechanical power, since not only wood but even rocks can be split by it; which would be impossible to effect by the lever, wheel and axle, or pulley: for the force of the blow, or stroke, shakes the cohering parts, and thereby makes them separate the more easily.

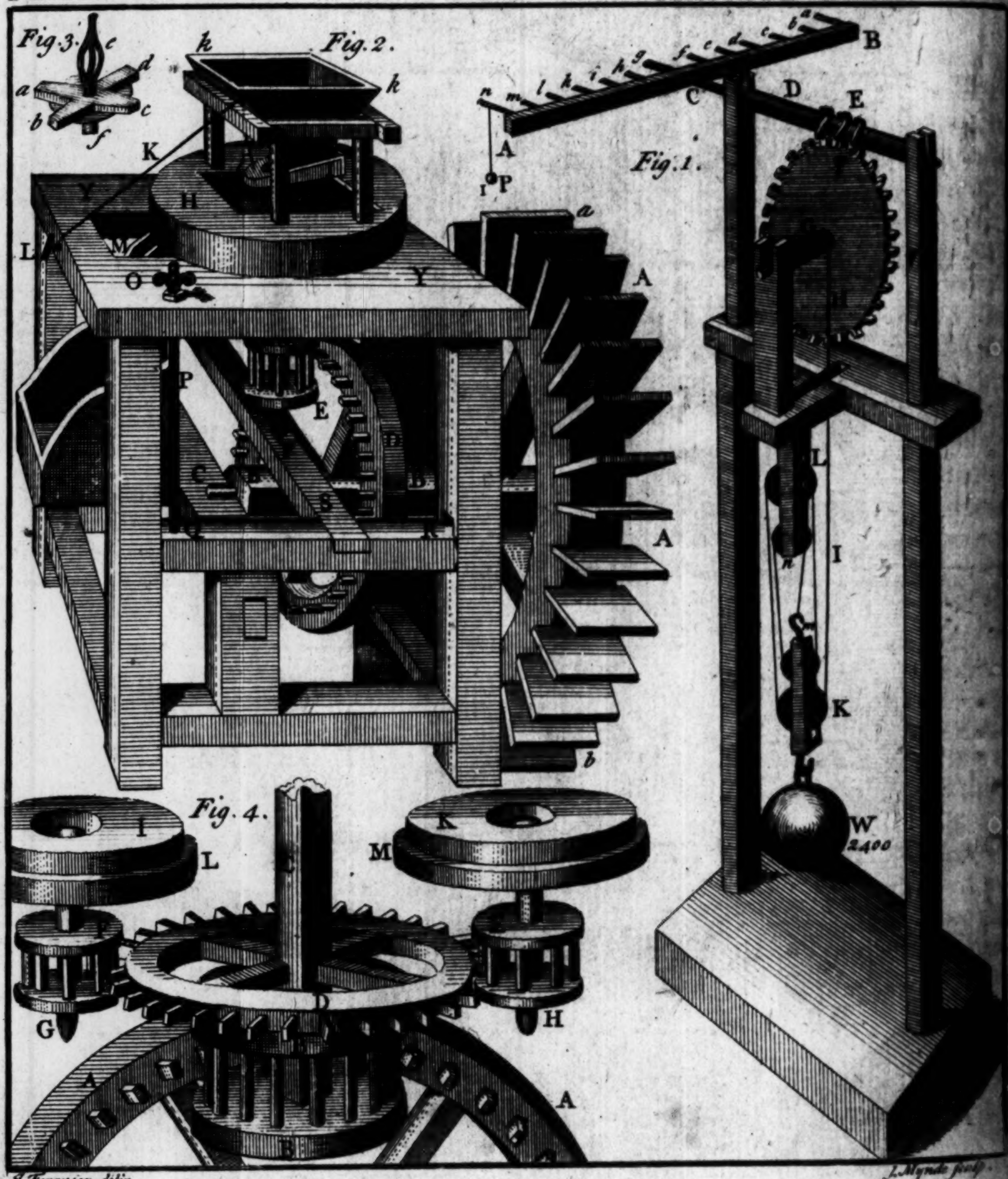
 6. The

The *screw.* 6. The sixth and last mechanical power is the *screw*; which cannot properly be called a simple machine, because it is never used without the application of a lever or winch to assist in turning it: and then it becomes a compound engine of a very great force either in pressing the parts of bodies close together, or in raising great weights. It may be conceived to be made by cutting a piece of paper *ABC* (Fig. 12.) into the form of an inclined plane or half wedge, and then coiling it round a cylinder *AB* (Fig. 13). And here it is evident, that the winch *E* must turn the cylinder once round before the weight of resistance *D* can be moved from one spiral winding to another, as from *d* to *c*: therefore, as much as the circumference of a circle described by the handle of the winch is greater than the interval or distance between the spirals, so much is the force of the screw. Thus, supposing the distance between the spirals to be half an inch, and the length of the winch to be twelve inches, the circle described by the handle of the winch where the power acts will be 76 inches nearly, or about 152 halfinches, and consequently 152 times as great as the distance between the spirals: and therefore a power at the handle, whose intensity is equal to no more than a single pound, will balance 152 pounds acting against the screw; and as much additional force, as is sufficient to overcome the friction, will raise the 152 pounds; and the velocity of the power will be to the velocity of the weight, as 152 to 1. Hence it appears, that the longer the winch be made, and the nearer the spirals are to one another, so much the greater is the force of the screw.

Fig. 12, 13.

Fig. 14. A machine for shewing the force or power of the screw may be contrived in the following manner. Let the wheel *G* have a screw *ab* on its

PLATE VII.



J. Ferguson delin. J. Mynde sculp.

its axis, working in the teeth of the wheel *D*, which suppose to be 48 in number. It is plain, that for every time the wheel *C* and screw *a b* are turned round by the winch *A*, the wheel *D* will be moved one tooth by the screw; and therefore, in 48 revolutions of the winch, the wheel *D* will be turned once round. Then, if the circumference of a circle described by the handle of the winch be equal to the circumference of a groove *e* round the wheel *D*, the velocity of the handle will be 48 times as great as the velocity of any given point in the groove. Consequently, if a line *G* (above number 48) goes round the groove *e*, and has a weight of 48 pounds hung to it below the pedestal *E F*, a power equal to one pound at the handle will balance and support the weight.—To prove this by experiment, let the circumferences of the grooves of the wheels *C* and *D* be equal to one another; and then if a weight *H* of one pound be suspended by a line going round the groove of the wheel *C*, it will balance a weight of 48 pounds hanging by the line *G*; and a small addition to the weight *H* will cause it to descend, and so raise up the other weight.

If the line *G*, instead of going round the groove *e* of the wheel *D*, goes round its axle *I*; the power of the machine will be as much increased, as the circumference of the groove *e* exceeds the circumference of the axle: which, supposing it to be six times, then one pound at *H* will balance 6 times 48, or 288 pounds hung to the line on the axle: and hence the power or advantage of this machine will be as 288 to 1. That is to say, a man, who by his natural strength could lift an hundred weight, will be

able to raiſe 288 hundred, or 14 $\frac{8}{20}$ ton weight by this engine.

Plate VII. Fig. 1.

A combination of all the mechanical powers.

But the following engine is ſtill more powerful, on account of its having the addition of four pulleys: and in it we may look upon all the mechanical powers as combined together, even if we take in the balance. For as the axis *D* of the bar *AB* is in its middle at *C*, it is plain that if equal weights are ſuſpended upon any two pins equi-diſtant from the axis *C*, they will counterpoiſe each other.—It becomes a lever by hanging a ſmall weight *P* upon the pin *n*, and a weight as much heavier upon either of the pins *b*, *c*, *d*, *e*, or *f*, as is in proportion to the pins being ſo much nearer the axis. The wheel and axle *FG* is evident; ſo is the ſcrew *E* which takes in the inclined plane, and with it the half wedge. Part of a cord goes round the axle, the reſt under the lower pulleys *K*, *m*, over the upper pulleys *L*, *n*, and then it is tied to a hook at *m* in the lower or moveable block, on which hangs the weight *W*.

In this machine, if the wheel *F* has 30 teeth, it will be turned once round in thirty revolutions of the bar *AB*, which is fixt on the axis *D* of the ſcrew *E*: if the length of the bar is equal to twice the diameter of the wheel, the pins *a* and *n* at the ends of the bar will move 60 times as faſt as the teeth of the wheel do: and conſequently, one ounce at *P* will balance 60 ounces hung upon a tooth at *q* in the horizontal diameter of the wheel. Then, if the diameter of the wheel *F* is 10 times as great as the diameter of the axle *G*, the wheel will have 10 times the velocity of the axle; and therefore one ounce *P* at the end of the lever *AC* will balance 10 times 60 or 600 ounces hung to the rope *H* which goes round

round the axle. Laſtly, if four pulleys be added, they will make the velocity of the lower block *K*, and weight *W*, four times leſs than the velocity of the axle: and this being the laſt power in the machine, which is four times as great as that gained by the axle, it makes the whole power of the machine 4 times 600, or 2400. So that a man who could lift one hundred weight in his arms, by his natural ſtrength, would be able to raiſe 2400 hundred weight by this engine.—But it is here as in all other mechanical caſes; for the time loſt is always as much as the power gained, becauſe the velocity with which the power moves will ever exceed the velocity with which the weight riſes, as much as the intenſity of the weight exceeds the intenſity of the power.

The friction of the ſcrew itſelf is very conſiderable; and there are few compound engines, but what, upon account of the friction of the parts againſt one another, will require a third part of more power to work them when loaded, than what is ſufficient to conſtitute a balance between the weight and the power.

LECT. IV.

Of mills, cranes, wheel-carriages, and the engine for driving piles.

AS theſe machines are ſo univerſally uſeful, it would be ridiculous to make any apology for deſcribing them.

In a common *breaſt-mill*, where the fall of water may be about ten feet, *AA* is the great wheel, which is generally about 17 or 18 feet in diameter, Plate VII. Fig. 2. A common mill.

diameter, reckoned from the outermoſt edge of any float-board at *a* to that of its oppoſite float at *b*. To this wheel the water is conveyed through a channel, and ſo falling upon the wheel, turns it round.

On the axis *BB* of this wheel, and within the mill houſe, is a wheel *D*, about 8 or 9 feet diameter, having 61 cogs, which turn a trundle *E* containing ten upright ſtaves or rounds; and when theſe are the number of cogs and rounds, the trundle will make $6\frac{1}{10}$ revolutions for one revolution of the wheel.

The trundle is fixt upon a ſtrong iron axis called the ſpindle, the lower end of which turns in a braſs foot, fixt at *F*, in the horizontal beam *ST* called the bridge-tree; and the upper part of the ſpindle turns in a wooden buſh fixt into the nether millſtone which lies upon beams in the floor *YY*. The top part of the ſpindle above the buſh is ſquare, and goes into a ſquare hole in a ſtrong iron croſs *abcd*, (ſee Fig. 3.) called the rynd; under which, and cloſe to the buſh, is a round piece of thick leather upon the ſpindle, which it turns round at the ſame time as it does the rynd.

The rynd is let into grooves in the under ſurface of the running millſtone *G* (Fig. 2.) and ſo turns it round in the ſame time that the trundle *E* is turned round by the cog-wheel *D*. This millſtone has a large hole quite through its middle, called the eye of the ſtone, through which the middle part of the rynd and upper end of the ſpindle may be ſeen; whilſt the four ends of the rynd lie hid below the ſtone in their grooves.

The end *T* of the bridge-tree *TS* (which ſupports the upper millſtone *G* upon the ſpindle) is fixed into a hole in the wall; and the end *S* is let into a beam *QR* called the brayer, whoſe end *R* remains

remains fixt in a mortiſe: and its other end *Q* hangs by a ſtrong iron rod *P* which goes through the floor *YY*, and has a ſcrew-nut on its top at *O*; by the turning of which nut, the end *Q* of the brayer is raiſed or depreſſed at pleaſure; and conſequently the bridge-tree *TS* and upper millſtone. By this means, the upper millſtone may be ſet as cloſe to the under one, or raiſed as high from it, as the miller pleaſes. The nearer the millſtones are to one another, the finer they grind the corn, and the more remote from one another, the coarſer.

The upper millſtone *G* is incloſed in a round box *H*, which does not touch it any where; and is about an inch diſtant from its edge all around. On the top of this box ſtands a frame for holding the hopper *kk*, to which is hung the ſhoe *I* by two lines faſtened to the hind-part of it, fixed upon hooks in the hopper, and by one end of the crook-ſtring *K* faſtened to the fore-part of it at *i*; the other end being twiſted round the pin *L*. As the pin is turned one way, the ſtring draws up the ſhoe cloſer to the hopper, and ſo leſſens the aperture between them; and as the pin is turned the other way, it lets down the ſhoe, and enlarges the aperture.

If the ſhoe be drawn up quite to the hopper, no corn can fall from the hopper into the mill; if it be let a little down, ſome will fall: and the quantity will be more or leſs, according as the ſhoe is more or leſs let down. For the hopper is open at bottom, and there is a hole in the bottom of the ſhoe, not directly under the bottom of the hopper, but forwarder towards the end *i*, over the middle of the eye of the millſtone.

There is a ſquare hole in the top of the ſpindle, in which is put the feeder *e*: this feeder (as the Fig. 3.

ſpindle

ſpindle turns round) jogs the ſhoe three times in each revolution, and ſo cauſes the corn to run conſtantly down from the hopper, through the ſhoe, into the eye of the millſtone, where it falls upon the top of the rynd, and is, by the motion of the rynd, and the leather under it, thrown below the upper ſtone, and ground between it and the lower one. The violent motion of the ſtone creates a centrifugal force in the corn going round with it, by which means it gets farther and farther from the center, as in a ſpiral, in every revolution, until it be thrown quite out; and, being then ground, it falls through a ſpout *M*, called the mill-eye, into the trough *N*.

When the mill is fed too faſt, the corn bears up the ſtone, and is ground too coarſe; and beſides, it clogs the mill ſo as to make it go too ſlow. When the mill is too ſlowly fed, it goes too faſt, and the ſtones by their attrition are apt to ſtrike fire againſt one another. Both which inconveniencies are avoided by turning the pin *L* backwards or forwards, which draws up or lets down the ſhoe; and ſo regulates the feeding as the miller ſees convenient.

The heavier the running millſtone is, and the greater the quantity of water that falls upon the wheel, ſo much the faſter will the mill bear to be fed; and conſequently ſo much the more it will grind. And on the contrary, the lighter the ſtone, and the leſs the quantity of water, ſo much ſlower muſt the feeding be. But when the ſtone is conſiderably wore, and become light, the mill muſt be fed ſlowly at any rate; otherwiſe the ſtone will be too much borne up by the corn under it, which will make the meal coarſe.

The quantity of power required to turn a heavy millſtone is but very little more than what is

ſufficient to turn a light one: for as it is ſup-ported upon the ſpindle by the bridge-tree *S T*, and the end of the ſpindle that turns in the braſs foot therein being but ſmall, the odds ariſing from the weight is but very inconſiderable in its action againſt the power or force of the water. And beſides, a heavy ſtone has the ſame advantage as a heavy fly; namely, that it regulates the motion much better than a light one.

In order to cut and grind the corn, both the upper and under millſtones have channels or furrows cut into them, proceeding obliquely from the center towards the circumference. And theſe furrows are each cut perpendicularly on one ſide and obliquely on the other into the ſtone, which gives each furrow a ſharp edge, and in the two ſtones they come, as it were, againſt one another like the edges of a pair of ſciſſars: and ſo cut the corn, to make it grind the eaſier when it falls upon the places between the furrows. Theſe are cut the ſame way in both ſtones when they lie upon their backs, which makes them run croſs ways to each other when the upper ſtone is inverted by turning its furrowed ſurface towards that of the lower. For, if the furrows of both ſtones lay the ſame way, a great deal of the corn would be driven onward in the lower furrows, and ſo come out from between the ſtones without ever being cut.

When the furrows become blunt and ſhallow by wearing, the running ſtone muſt be taken up, and both ſtones new dreſt with a chiſel and hammer. And every time the ſtone is taken up, there muſt be ſome tallow put round the ſpindle upon the buſh, which will ſoon be melted by the heat the ſpindle acquires from its turning and rubbing againſt the buſh, and ſo will get in betwixt

betwixt them: otherwise the bush would take fire in a very little time.

The bush must embrace the spindle quite close, to prevent any shake in the motion, which would make some parts of the stones grate and fire against each other; whilst other parts of them would be too far asunder, and by that means spoil the meal in grinding.

Whenever the spindle wears the bush so as to begin to shake in it, the stone must be taken up, and a chisel drove into several parts of the bush; and when it is taken out, wooden wedges must be driven into the holes; by which means the bush will be made to embrace the spindle close all around it again. In doing this, great care must be taken to drive equal wedges into the bush on opposite sides of the spindle; otherwise it will be thrown out of the perpendicular, and so hinder the upper stone from being set parallel to the under one, which is absolutely necessary for making good work. When any accident of this kind happens, the perpendicular position of the spindle must be restored by adjusting the bridge-tree *ST* by proper wedges put between it and the brayer *QR*.

It often happens, that the rynd is a little wrenched in laying down the upper stone upon it; or is made to sink a little lower upon one side of the spindle than on the other; and this will cause one edge of the upper stone to drag all around upon the other, whilst the opposite edge will not touch. But this is easily set to rights, by raising the stone a little with a lever, and putting bits of paper, cards or thin chips, betwixt the rynd and the stone.

The diameter of the upper stone is generally about six feet, the lower stone about an inch more:

more: and the upper ſtone when new contains about $22\frac{1}{2}$ cubic feet, which weighs ſomewhat more than 1900 pounds. A ſtone of this diameter ought never to go more than 60 times round in a minute; for if it turns faſter, it will heat the meal.

The grinding ſurface of the under ſtone is a little convex from the edge to the center, and that of the upper ſtone a little more concave: ſo that they are fartheſt from one another in the middle, and come gradually nearer towards the edges. By this means, the corn at its firſt entrance between the ſtones is only bruiſed; but as it goes farther on towards the circumference or edge, it is cut ſmaller and ſmaller; and at laſt finely ground juſt before it comes out from between them.

The water-wheel muſt not be too large, for if it be, its motion will be too ſlow; nor too little, for then it will want power. And for a mill to be in perfection, the floats of the wheel ought to move with a third part of the velocity of the water, and the ſtone to turn round once in a ſecond of time.

Such a mill as this, with a fall of water about $7\frac{1}{2}$ feet, will require about 32 hogſheads every minute to turn the wheel with a third part of the velocity with which the water falls; and to overcome the reſiſtance ariſing from the friction of the geers and attrition of the ſtones in grinding the corn.

The greater fall the water has, the leſs quantity of it will ſerve to turn the mill. The water is kept up in the mill-dam, and let out by a ſluice called the penſtock, when the mill is to go. When the penſtock is drawn up by means of a lever, it opens a paſſage through which the water

flows

flows to the wheel: and when the mill is to be ſtopt, the penſtock is let down, which ſtops the water from falling upon the wheel.

A leſs quantity of water will turn an overſhot-mill (where the wheel has buckets inſtead of float-boards) than a breaſt-mill where the fall of the water ſeldom exceeds half the height *Ab* of the wheel. So that, where there is but a ſmall quantity of water, and a fall great enough for the wheel to lie under it, the bucket (or overſhot) wheel is always uſed. But where there is a large body of water, with a little fall, the breaſt or float-board wheel muſt take place. Where the water runs only upon a little declivity, it can act but ſlowly upon the under part of the wheel at *b*; in which caſe, the motion of the wheel will be very ſlow: and therefore, the floats ought to be very long, though not high, that a large body of water may act upon them; ſo that what is wanting in velocity may be made up in power: and then the cog-wheel may have a greater number of cogs in proportion to the rounds in the trundle, in order to give the millſtone a ſufficient degree of velocity.

They who have read what is ſaid in the firſt lecture, concerning the acceleration of bodies falling freely by the power of gravity acting conſtantly and uniformly upon them, may perhaps aſk, why ſhould the motion of the wheel be equable, and not accelerated, ſince the water acts conſtantly and uniformly upon it? The plain anſwer is, that the velocity of the wheel can never be ſo great as the velocity of the water that turns it; for, if it ſhould not become ſo great, the power of the water would be quite loſt upon the wheel, and then there would be no proper force to overcome the friction of the geers

geers and attrition of the ſtones. Therefore, the velocity with which the wheel begins to move, will increaſe no longer than till its *momentum* or force is balanced by the reſiſtance of the machine; and then the wheel will go on with an equable motion.

[If the cog-wheel *D* be made about 18 inches diameter, with 30 cogs, the trundle as ſmall in proportion, with 10 ſtaves, and the millſtones be each about two feet in diameter, and the whole work be put into a ſtrong frame of wood, as repreſented in the figure, the engine will be a hand-mill for grinding corn or malt in private families. And then, it may be turned by a winch inſtead of the wheel *AA*: the millſtone making three revolutions for every one of the winch. If a heavy fly be put upon the axle *B*, near the winch, it will help to regulate the motion.] *A hand-mill.*

If the cogs of the wheel and rounds of the trundle could be put in as exactly as the teeth are cut in the wheels and pinions of a clock, then the trundle might divide the wheel exactly: that is to ſay, the trundle might make a given number of revolutions for one of the wheel, without a fraction. But as any exact number is not neceſſary in mill-work, and the cogs and rounds cannot be ſet in ſo truly as to make all the intervals between them equal; a ſkilful mill-wright will always give the wheel what he calls *a hunting cog*; that is, one more than what will anſwer to an exact diviſion of the wheel by the trundle. And then, as every cog comes to the trundle, it will take the next ſtaff or round behind the one which it took in the former revolution: and by that means, will wear all the parts of the cogs and rounds which work upon one another equally, and to equal diſtances from

one another in a little time; and so make a true uniform motion throughout the whole work. Thus, in the above water-mill, the trundle has 10 staves, and the wheel 61 cogs.

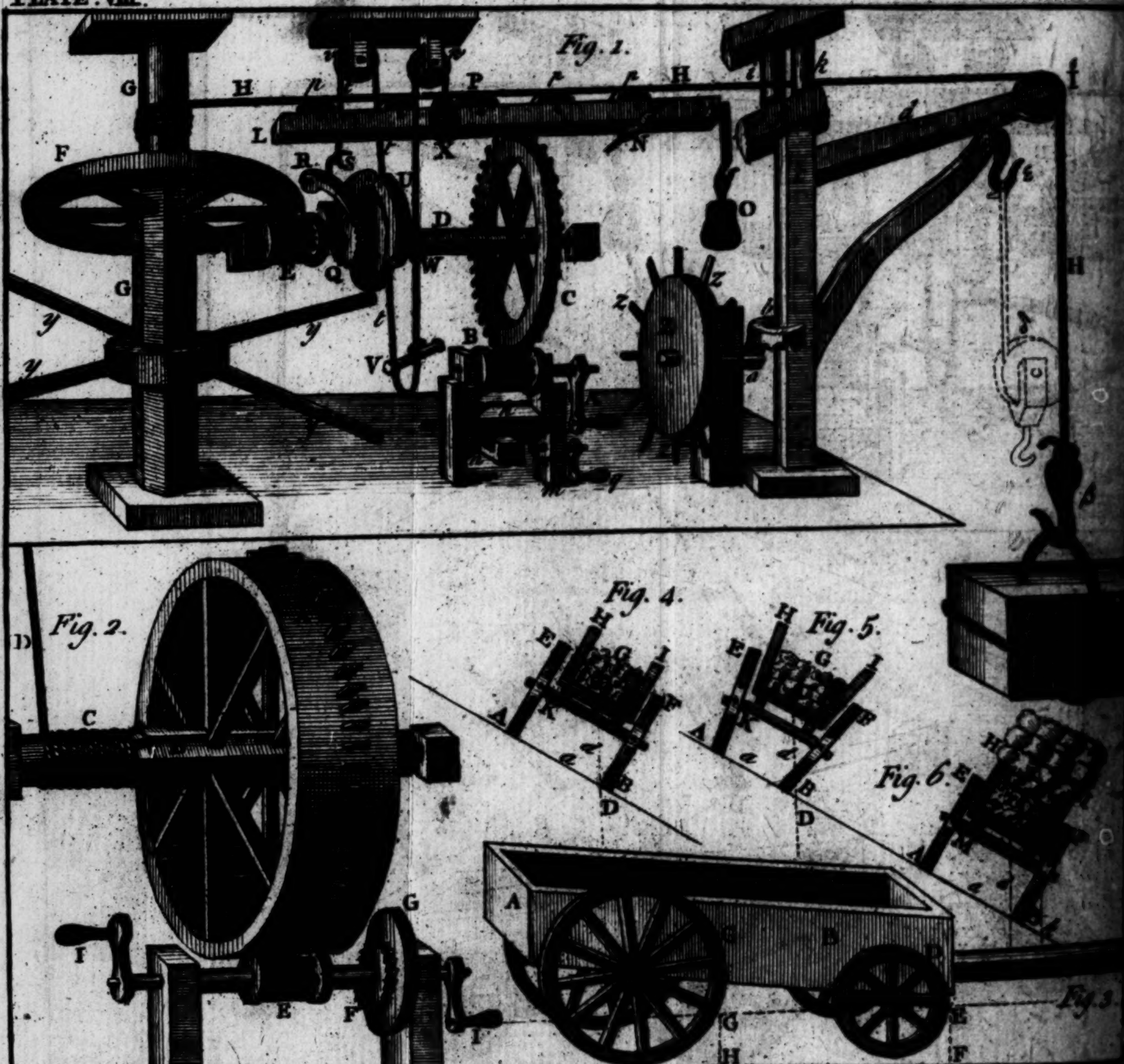
Fig. 4. Sometimes, where there is a sufficient quantity of water, the cog-wheel *A A* turns a large trundle *B B*, on whose axis *C* is fixed the horizontal wheel *D*, with cogs all round its edge, turning two trundles *E* and *F* at the same time, whose axes or spindles *G* and *H* turn two millstones *I* and *K*, upon the fixed stones *L* and *M*. And when there is not work for them both, either may be made to lie quiet, by taking out one of the staves of its trundle, and turning the vacant place towards the cog-wheel *D*. And there may be a wheel fixt on the upper end of the great upright axle *C* for turning a couple of boulting-mills; and other work for drawing up the sacks, fanning and cleaning the corn, sharpening of tools, &c.

A horse-mill. If, instead of the cog-wheel *A A* and trundle *B B*, horizontal levers be fixed into the axle *C*, below the wheel *D*; then, horses may be put to these levers for turning the mill: which is often done where water cannot be had for that purpose.

A wind-mill. The working parts of a wind-mill differ very little from those of a water-mill; only the former is turned by the action of the wind upon four sails, every one of which ought (as is generally believed) to make an angle of $54\frac{3}{4}$ degrees with a plane perpendicular to the axis on which the arms are fixt for carrying them. It being demonstrable, that when the sails are set to such an angle, and the axis turned end-ways toward the wind, the wind has the greatest power upon the sails. But this angle answers only to the case of

a vast

PLATE VIII.



J. Ferguson delin.

J. Mynde sc.

a vane or sail just beginning to move *: for, when the vane has a certain degree of motion, it yields to the wind; and then that angle must be increased to give the wind its full effect.

Again, the increase of this angle should be different, according to the different velocities from the axis to the extremity of the vane. At the axis it should be $54\frac{3}{7}$ degrees, and thence continually increase, giving the vane a twist, and so causing all the ribs of the vane to lie in different planes.

Lastly, these ribs ought to decrease in length from the axis to the extremity, giving the vane a curvilineal form; so that no part of the force of any one rib be spent upon the rest, but all move on independant of each other. All this is required to give the sails of a wind-mill their true form: and we see both the twist and the diminution of the ribs exemplified in the wings of birds.

It is almost incredible to think with what velocity the tips of the sails move when acted upon by a moderate gale of wind. I have several times counted the number of revolutions made by the sails in ten or fifteen minutes; and from the length of the arms from tip to tip, have computed, that if a hoop of that diameter was to run upon the ground with the same velocity that it would move if put upon the sail-arms, it would go upwards of 30 miles in an hour.

As the ends of the sails nearest the axis cannot move with the same velocity that the tips or farthest ends do, although the wind acts equally strong upon them; perhaps a better position than that of stretching them along the arms directly from the center of motion, might be to

* See MAC LAURIN's Fluxions, near the end.

have them ſet perpendicularly acroſs the farther ends of the arms, and there adjuſted lengthwiſe to the proper angle. For, in that caſe, both ends of the ſails would move with the ſame velocity; and being farther from the center of motion, they would have ſo much the more power: and then, there would be no occaſion for having them ſo large as they are generally made; which would render them lighter, and conſequently, there would be ſo much the leſs friction on the thick neck of the axle where it turns in the wall.

A *crane*. A *crane* is an engine by which great weights are raiſed to certain heights, or let down to certain depths. It conſiſts of wheels, axles, pulleys, ropes, and a gib or gibbet. When the rope *H* is hooked to the weight *K*, a man turns the winch *A*, on the axis whereof is the trundle *B*, which turns the wheel *C*, on whoſe axis *D* is the trundle *E*, which turns the wheel *F* with its upright axis *G*, on which the great rope *HH* winds as the wheel turns; and going over a pulley *I* at the end of the arm *d* of the gib *ccde*, it draws up the heavy burthen *K*; which, being raiſed to a proper height, as from a ſhip to the quay, is then brought over the quay by pulling the wheel *Z* round by the handles *z*, *z*, which turns the gib by means of the half wheel *b* fixt on the gib-poſt *cc*, and the ſtrong pinion *a* fixt on the axis of the wheel *Z*. This wheel gives the man that turns it an abſolute command over the gib, ſo as to prevent it from taking any unlucky ſwing, ſuch as often happens when it is only guided by a rope tied to its arm *d*; and people are frequently hurt, ſometimes killed, by ſuch accidents.

Plate VIII. Fig. 1.

The

The great rope goes between two upright rollers *i* and *k*, which turn upon gudgeons in the fixed beams *f* and *g*; and as the gib is turned towards either ſide, the rope bends upon the roller next that ſide. Were it not for theſe rollers, the gib would be quite unmanageable; for the moment it were turned ever ſo little towards any ſide, the weight *K* would begin to deſcend, becauſe the rope would be ſhortened between the pulley *I* and axis *G*; and ſo the gib would be pulled violently to that ſide, and either be broke to pieces, or break every thing that came in its way. Theſe rollers muſt be placed ſo, that the ſides of them, round which the rope bends, may keep the middle of the bended part directly even with the center of the hole in which the upper gudgeon of the gib turns in the beam *f*. The truer theſe rollers are placed, the eaſier the gib is managed, and the leſs apt to ſwing either way by the force of the weight *K*.

A ratchet-wheel *Q* is fixt upon the axis *D*, near the trundle *E*; and into this wheel falls the catch or click *R*. This hinders the machine from running back by the weight of the burthen *K*, if the man who raiſes it ſhould happen to be careleſs, and ſo leave off working at the winch *A* ſooner than he ought to do.

When the burthen *K* is raiſed to its proper height from the ſhip, and brought over the quay by turning the gib about, it is let down gently upon the quay, or into a cart ſtanding thereon, in the following manner: A man takes hold of the rope *t t* (which goes over the pulley *v*, and is tied to a hook at *S* in the catch *R*) and ſo diſengages the catch from the ratchet-wheel *Q*; and then, the man at the winch *A* turns it

backward, and lets down the weight *K*. But if the weight pulls too hard againſt this man, another lays hold of the handle *V*, and by pulling it downward, draws the gripe *U* cloſe to the wheel *Y*, which, by rubbing hard againſt the gripe, hinders the too quick deſcent of the weight; and not only ſo, but even ſtops it at any time, if required. By this means, heavy goods may be either raiſed or let down at pleaſure, without any danger of hurting the men who work the engine.

When part of the goods are craned up, and the rope is to be let down for more, the catch *R* is firſt diſengaged from the ratchet-wheel *Q*, by pulling the cord *t*; then the handle *q* is turned half round backward, which, by the crank *n n* in the piece *o*, pulls down the frame *b* between the guides *m* and *m* (in which it ſlides in a groove) and ſo diſengages the trundle *B* from the wheel *C*: and then, the heavy hook *β* at the end of the rope *H* deſcends by its own weight, and turns back the great wheel *F* with its trundle *E*, and the wheel *C*; and this laſt wheel acts like a fly againſt the wheel *F* and hook *β*; and ſo hinders it from going down too quick; whilſt the weight *X* keeps up the gripe *U* from rubbing againſt the wheel *Y*, by means of a cord going from the weight, over the pulley *w* to the hook *W* in the gripe; ſo that the gripe never touches the wheel, unleſs it be pulled down by the handle *V*.

When the crane is to be ſet at work again, for drawing up another burthen, the handle *q* is turned half round forwards; which, by the crank *n n*, raiſes up the frame *b*, and cauſes the trundle *B* to lay hold of the wheel *C*; and then, by

by turning the winch *A*, the burthen of goods *K* is drawn up as before.

The crank *n n* turns pretty ſtiff in the mortiſe near *o*, and ſtops againſt the farther end of it when it has got juſt a little beyond the perpendicular; ſo that it can never come back of itſelf: and therefore, the trundle *B* can never come away from the wheel *C*, until the handle *q* be turned half round.

The great rope runs upon rollers in the lever *L M*, which keep it from bending between the axle at *G* and the pulley *I*. This lever turns upon the axis *N* by means of the weight *O*, which is juſt ſufficient to keep its end *L* up to the rope; ſo that, as the great axle turns, and the rope coils round it, the lever riſes with the rope, and prevents the coilings from going over one another.

The power of this crane may be eſtimated thus: ſuppoſe the trundle *B* to have 13 ſtaves or rounds, and the wheel *C* to have 78 ſpur cogs; the trundle *E* to have 14 ſtaves, and the wheel *F* 56 cogs. Then, by multiplying the ſtaves of the trundles, 13 and 14, into one another, their product will be 182; and by multiplying the cogs of the wheels, 78 and 56, into one another, their product will be 4368, and dividing 4368 by 182, the quotient will be 24; which ſhews that the winch *A* makes 24 turns for one turn of the wheel *F* and its axle *G* on which the great rope or chain *H I H* winds. So that, if the length or radius of the winch *A* were only equal to half the diameter of the great axle *G*, added to half the thickneſs of the rope *H*, the power of the crane would be as 24 to 1: but the radius of the winch being double the above length, it doubles the ſaid power, and ſo makes it as 48 to 1: in which caſe, a man may raiſe 48 times as much weight

by this engine as he could do by his natural ſtrength without it, making proper allowance for the friction of the working parts.—Two men may work at once, by having another winch on the oppoſite end of the axis of the trundle under *B*; and ſo make the power ſtill double.

If this power be thought greater than what may be generally wanted, the wheels may be made with fewer cogs in proportion to the ſtaves in the trundles; and ſo the power may be of whatever degree is judged to be requiſite. But if the weight be ſo great as will require yet more power to raiſe it (ſuppoſe a double quantity) then the rope *H* may be put under a moveable pulley, as δ, and the end of it tied to a hook in the gib at ε; which will give a double power to the machine, and ſo raiſe a double weight hooked to the block of the moveable pulley.

When only ſmall burthens are ſo raiſed, this may be quickly done by men puſhing the axle *G* round by the handſpokes *y*, *y*, *y*, *y*; having firſt diſengaged the trundle *B* from the wheel *C*: and then, this wheel will only act as a fly upon the wheel *F*; and the catch *R* will prevent its running back, if the men ſhould inadvertently leave off puſhing before the burthen be unhooked from β.

Laſtly, when very heavy burthens are to be raiſed, which might endanger the breaking of the cogs in the wheel *F*; their force againſt theſe cogs may be much abated by men puſhing round the handſpokes *y*, *y*, *y*, *y*, whilſt the man at *A* turns the winch.

I have only ſhewn the working parts of this crane, without the whole of the beams which ſupport them; knowing that theſe are eaſily ſuppoſed,

ſuppoſed, and that if they had been drawn, they would have hid a great deal of the working parts from ſight, and alſo confuſed the figure.

Another crane. Fig. 2.

Another very good *crane* is made in the following manner. *A A* is a great wheel turned by men walking within it at *H*. On the part *C*, of its axle *B C*, the great rope *D* is wound as the wheel turns; and this rope draws up goods in the ſame way as the rope *H H* does in the above-mentioned crane, the gib-work here being ſuppoſed to be of the ſame ſort. But theſe cranes are very dangerous to the men in the wheel; for, if any of the men ſhould chance to fall, the burthen will make the wheel run back and throw them all about within it; which often breaks their limbs, and ſometimes kills them. The late ingenious Mr. *Padmore* of Briſtol, (whoſe contrivance the forementioned crane is, ſo far as I can remember its conſtruction after ſeeing it once about twelve years ago *) obſerving this dangerous conſtruction, contrived a method for remedying it, by putting cogs all around the outſide of the wheel, and applying a trundle *E* to turn it; which increaſes the power as much as the number of cogs in the wheel is greater than the number of ſtaves in the trundle: and by putting a ratchet-wheel *F* on the axis of the trundle, (as in the above-mentioned crane) with a catch to fall into it, the great wheel is ſtopt from running back by the force of the weight, even if all the men in

* Since the firſt edition of this book was printed, I have ſeen the ſame crane again; and do find, that though the working parts are much the ſame as above deſcribed, yet the method of raiſing or lowering the trundle *B*, and the catch *R*, are better contrived than I have deſcribed them.

it ſhould leave off walking. And by one man working at the winch *I*, or two men at the oppoſite winches when needful, the men in the wheel are much aſſiſted, and much greater weights are raiſed, than could be by men only within the wheel. Mr. *Padmore* put alſo a gripe-wheel *G* upon the axis of the trundle, which being pinched in the ſame manner as deſcribed in the former crane, heavy burthens may be let down without the leaſt danger. And before this contrivance, the lowering of goods was always attended with the utmoſt danger to the men in the wheel; as every one muſt be ſenſible of, who has ſeen ſuch engines at work.

And it is ſurpriſing that the maſters of wharfs and cranes ſhould be ſo regardleſs of the limbs, or even lives of their workmen, that excepting the late Sir *James Creed* of Greenwich, and ſome gentlemen at Briſtol, there is ſcarce an inſtance of any who has uſed this ſafe contrivance.

Wheel-carriages. The ſtructure of *wheel-carriages* is generally ſo well known, that it would be needleſs to deſcribe them. And therefore, we ſhall only point out ſome inconveniencies attending the common method of placing the wheels, and loading the waggons.

In coaches, and all other four-wheeled carriages, the fore-wheels are made of a leſs ſize than the hind ones, both on account of turning ſhort, and to avoid cutting the braces: otherwiſe, the carriage would go much eaſier if the fore-wheels were as high as the hind ones, and the higher the better, becauſe their motion would be ſo much the ſlower on their axles, and conſequently the friction proportionably taken off.

off. But carriers and coachmen give another reaſon for making the fore-wheels much lower than the hind-wheels; namely, that when they are ſo, the hind-wheels help to puſh on the fore ones: which is too unphiloſophical and abſurd to deſerve a refutation, and yet for their ſatisfaction we ſhall ſhew by experiment that it has no exiſtence but in their own imaginations.

It is plain that the ſmall wheels muſt turn as much oftener round than the great ones, as their circumferences are leſs. And therefore, when the carriage is loaded equally heavy on both axles, the fore-axle muſt endure as much more friction, and conſequently wear out as much ſooner, than the hind-axle, as the fore-wheels are leſs than the hind ones. But the great misfortune is, that all the carriers to a man do obſtinately perſiſt, againſt the cleareſt reaſon and demonſtration, in putting the heavier part of the load upon the fore-axle of the waggon; which not only makes the friction greateſt where it ought to be leaſt, but alſo preſſeth the fore-wheels deeper into the ground than the hind-wheels, notwithſtanding the fore-wheels, being leſs than the hind ones, are with ſo much the greater difficulty drawn out of a hole or over an obſtacle, even ſuppoſing the weights on their axles were equal. For the difficulty, with equal weights, will be as the depth of the hole or height of the obſtacle is to the ſemidiameter of the wheel. Thus, if we ſuppoſe the ſmall wheel *D* of the waggon *AB* to fall into a hole of the depth *EF*, which is equal to the ſemidiameter of the wheel, and the waggon to be drawn horizontally along; it is evident, that the point *E* of the ſmall wheel will be drawn directly againſt the top of the hole; and therefore, Fig. 3.

fore, all the power of horſes and men will not be able to draw it out, unleſs the ground gives way before it. Whereas, if the hind-wheel *C* falls into ſuch a hole, it ſinks not near ſo deep in proportion to its ſemidiameter; and therefore, the point *G* of the large wheel will not be drawn directly, but obliquely, againſt the top of the hole; and ſo will be eaſily got out of it. Add to this, that ſince a ſmall wheel will often ſink to the bottom of a hole, in which a great wheel will go but a very little way, the ſmall wheels ought in all reaſon to be loaded with leſs weight than the great ones: and then the heavier part of the load would be leſs jolted upward and downward, and the horſes tired ſo much the leſs, as their draught raiſed the load to leſs heights.

It is true, that when the waggon-road is much up-hill, there may be danger in loading the hind part much heavier than the fore part; for then the weight would overhang the hind-axle, eſpecially if the load be high, and endanger tilting up the fore-wheels from the ground. In this caſe, the ſafeſt way would be to load it equally heavy on both axles; and then, as much more of the weight would be thrown upon the hind-axle than upon the fore one, as the ground riſes from a level below the carriage. But as this ſeldom happens, and when it does, a ſmall temporary weight laid upon the pole between the horſes would overbalance the danger; and this weight might he thrown into the waggon when it comes to level ground; it is ſtrange that an advantage ſo plain and obvious as would ariſe from loading the hind-wheels heavieſt, ſhould not be laid hold of, by complying with this method.

To confirm theſe reaſonings by experiment, let a ſmall model of a waggon be made, with its fore-wheels $2\frac{1}{2}$ inches in diameter, and its hind-wheels $4\frac{1}{2}$; the whole model weighing about 20 ounces. Let this little carriage be loaded any how with weights, and have a ſmall cord tied to each of its ends, equally high from the ground it reſts upon; and let it be drawn along a horizontal board, firſt by a weight in a ſcale hung to the cord at the fore part; the cord going over a pulley at the end of the board to facilitate the draught, and the weight juſt ſufficient to draw it along. Then, turn the carriage, and hang the ſcale and weight to the hind cord, and it will be found to move along with the ſame velocity as at firſt: which ſhews, that the power required to draw the carriage is all the ſame, whether the great or ſmall wheels are foremoſt; and therefore the great wheels do not help in the leaſt to puſh on the ſmall wheels in the road.

Hang the ſcale to the fore cord, and place the fore-wheels (which are the ſmall ones) in two holes, cut three eighth parts of an inch deep into the board; then put a weight of 32 ounces into the carriage, over the fore-axle, and an equal weight over the hind one: this done, put 44 ounces into the ſcale, which will be juſt ſufficient to draw out the fore-wheels: but if this weight be taken out of the ſcale, and one of 16 ounces put into its place, if the hind-wheels are placed in the holes, the 16 ounce weight will draw them out; which is little more than a third part of what was neceſſary to draw out the fore-wheels. This ſhews, that the larger the wheels are, the leſs power will draw the carriage, eſpecially on rough ground.

Put

Put 64 ounces over the axle of the hind-wheels, and 32 over the axle of the fore ones, in the carriage; and place the fore-wheels in the holes: then, put 38 ounces into the scale, which will just draw out the fore-wheels; and when the hind ones come to the hole, they will find but very little resistance, because they sink but a little way into it.

But shift the weights in the carriage, by putting the 32 ounces upon the hind axle, and the 64 ounces upon the fore one; and place the fore-wheels in the holes: then, if 76 ounces be put into the scale, it will be found no more than sufficient to draw out these wheels; which is double the power required to draw them out, when the lighter part of the load was put upon them: which is a plain demonstration of the absurdity of putting the heaviest part of the load in the fore part of the waggon.

Every one knows what an outcry was made by the generality, if not the whole body, of the carriers, against the broad-wheel act; and how hard it was to persuade them to comply with it, even though the government allowed them to draw with more horses, and carry greater loads, than usual. Their principal objection was, that as a broad wheel must touch the ground in a great many more points than a narrow wheel, the friction must of course be just so much the greater; and consequently, there must be so many more horses than usual, to draw the waggon. I believe that the majority of people were of the same opinion, not considering, that if the whole weight of the waggon and load in it bears upon a great many points, each sustains a proportionably less degree of weight and friction, than when it bears only upon a few points; so that

what

what is wanting in one, is made up in the other; and therefore will be juſt equal under equal degrees of weight, as may be ſhewn by the following plain and eaſy experiment.

Let one end of a piece of packthread be faſtened to a brick, and the other end to a common ſcale for holding weights: then, having laid the brick edgewiſe on a table, and let the ſcale hang under the edge of the table, put as much weight into the ſcale as will juſt draw the brick along the table. Then taking back the brick to its former place, lay it flat on the table, and leave it to be acted upon by the ſame weight in the ſcale as before, which will draw it along with the ſame eaſe as when it lay upon its edge. In the former caſe, the brick may be conſidered as a narrow wheel on the ground; and in the latter, as a broad wheel. And ſince the brick is drawn along with equal eaſe, whether its broad ſide or narrow edge touches the table, it ſhews that a broad wheel might be drawn along the ground with the ſame eaſe as a narrow one (ſuppoſing them equally heavy) even though they ſhould drag, and not roll, as they go along.

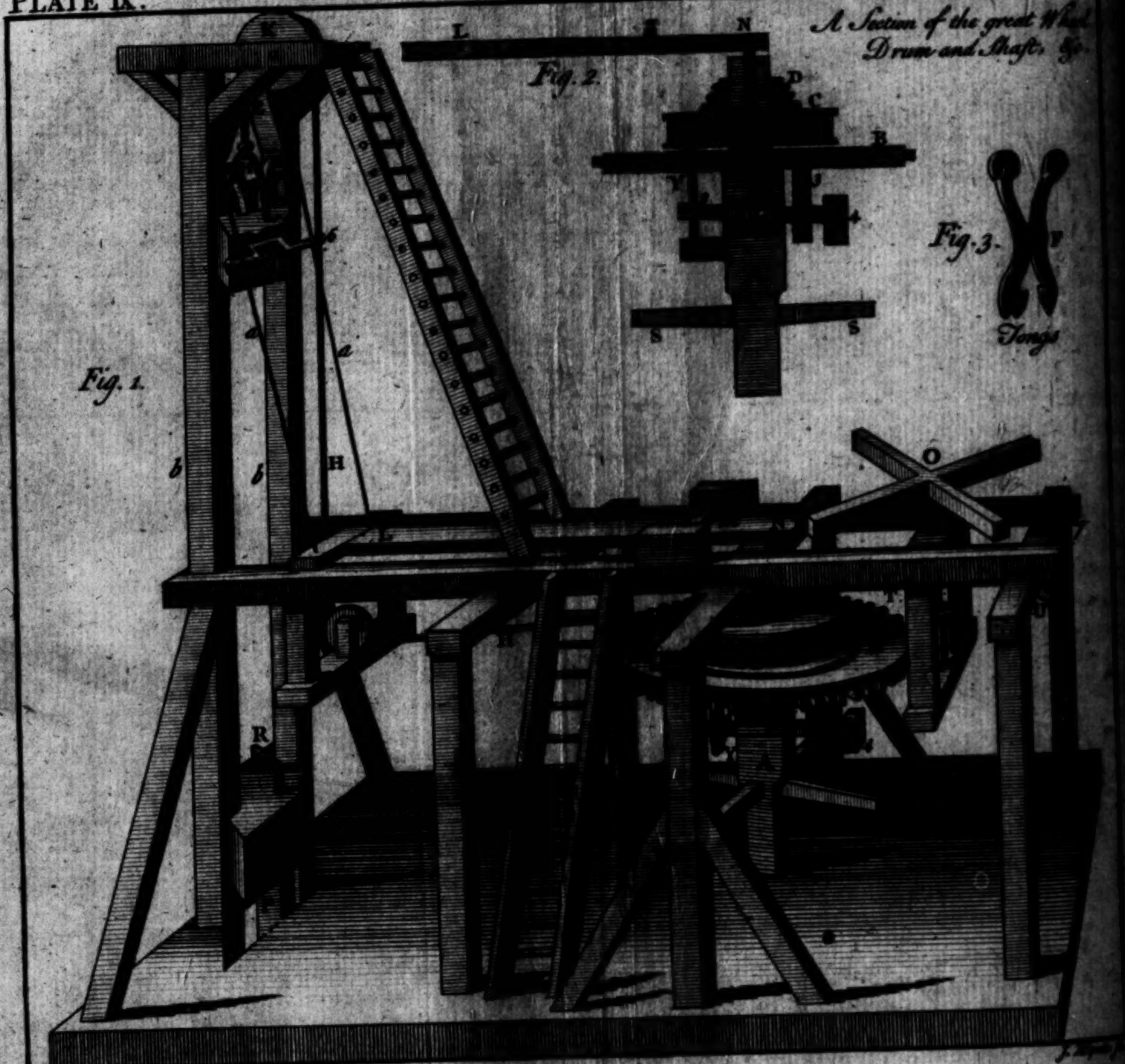
As narrow wheels are always ſinking into the ground, eſpecially when the heavieſt part of the load lies upon them, they muſt be conſidered as going conſtantly up hill, even on level ground. And their edges muſt ſuſtain a great deal of friction by rubbing againſt the ruts made by them. But both theſe inconveniencies are avoided by broad wheels; which, inſtead of cutting and ploughing up the roads, roll them ſmooth, and harden them; as experience teſtifies in places where they have been uſed, eſpecially either on wettiſh or ſandy ground: though after all it muſt be confeſſed, that they will not do in ſtiff clayey croſs roads;

roads; becauſe they would ſoon gather up ſo much clay as would be almoſt equal to the weight of an ordinary load.

If the wheels are always to go upon ſmooth and level ground, the beſt way would be to make the ſpokes perpendicular to the naves; that is, to ſtand at right angles to the axles; because they would then bear the weight of the load perpendicularly, which is the ſtrongeſt way for wood. But becauſe the ground is generally uneven, one wheel often falls into a cavity or rut when the other does not; and then it bears much more of the weight than the other does: in which caſe, concave or diſhing wheels are beſt, becauſe when one falls into a rut, and the other keeps upon high ground, the ſpokes become perpendicular in the rut, and therefore have the greateſt ſtrength when the obliquity of the load throws moſt of its weight upon them; while thoſe on the high ground have leſs weight to bear, and therefore need not be at their full ſtrength. So that the uſual way of making the wheels concave is by much the beſt.

The axles of the wheels ought to be perfectly ſtraight, that the rims of the wheels may be parallel to each other; for then they will move eaſieſt, becauſe they will be at liberty to go on ſtraight forwards. But in the uſual way of practice, the axles are bent downward at their ends; which brings the ſides of the wheels next the ground nearer to one another than their oppoſite or higher ſides are: and this not only makes the wheels to drag ſidewiſe as they go along, and gives the load a much greater power of cruſhing them than when they are parallel to each other, but alſo endangers the over-turning of the carriage when any wheel falls into a hole or rut; and

PLATE IX.


A Section of the great Wheel Drum and Shaft, &c.
Fig. 1.
Fig. 2.
Fig. 3.
Tongs
J. Ferguson delin.

when the carriage goes in a road which has one side lower than the other, as along the side of a hill. Thus (in the hind view of a waggon or cart) let *AE* and *BF* be the great wheels parallel to each other, on their straight axle *K*, and *HCI* the carriage loaded with heavy goods from *C* to *G*. Then, as the carriage goes on in the oblique road *AaB*, the center of gravity of the whole machine and load will be at *C**; and the line of direction *CdD* falling within the wheel *BF*, the carriage will not overset. But if the wheels be inclined to each other on the ground, as *AE* and *BF* are, and the machine be loaded as before, from *C* to *G*, the line of direction *CdD* falls without the wheel *BF*, and the whole machine tumbles over. When it is loaded with heavy goods (such as lead or iron) which lie low, it may travel safely upon an oblique road so long as the center of gravity is at *C*, and the line of direction *Cd* falls within the wheels; but if it be loaded high with lighter goods (such as wool-packs) from *C* to *L*, the center of gravity is raised from *C* to *K*, which throws the line of direction *Kk* without the lowest edge of the wheel *BF*, and then the load oversets the waggon.

Fig. 4.

* See page 13.

Fig. 5.

Fig. 4.

Fig. 6.

If there be some advantage from small fore-wheels, on account of the carriage turning more easily and short than it can be made to do when they are large; there is at least as great a disadvantage attending them, which is, that as their axle is below the level of the horses breasts, the horses not only have the loaded carriage to draw along, but also part of its weight to bear; which tires them sooner, and makes them grow much stiffer in their hams, than they would be if they drew on a level with the fore-axle. And for this reason, we find coach horses soon

ſoon become unfit for riding. So that on all accounts it is plain, that the fore-wheels of all carriages ought to be ſo high, as to have their axles even with the breaſt of the horſes; which would not only give the horſes a fair draught, but likewiſe cauſe the machine to be drawn by a leſs degree of power.

Plate IX. Fig. 1, 2. We ſhall conclude this lecture with a deſcription of Mr. *Vauloue*'s curious engine, which was made uſe of for driving the piles of Weſtminſter-bridge: and the reader may caſt his eyes upon the firſt and ſecond figures of the plate, in which the ſame letters of reference are annexed to the ſame parts, in order to explain thoſe in the ſecond, which are either partly or wholly hid in the firſt.

The *pile-engine.* *A* is the great upright ſhaft or axle, on which are the great wheel *B* and drum *C*, turned by horſes joined to the bars *S*, *S*. The wheel *B* turns the trundle *X*, on the top of whoſe axis is the fly *O*, which ſerves to regulate the motion, and alſo to act againſt the horſes, and keep them from falling when the heavy ram *Q* is diſcharged to drive the pile *P* down into the mud in the bottom of the river. The drum *C* is looſe upon the ſhaft *A*, but is locked to the wheel *B* by the bolt *Y*. On this drum the great rope *HH* is wound; one end of the rope being fixed to the drum, and the other to the follower *G*, to which it is conveyed over the pulleys *I* and *K*. In the follower *G* is contained the tongs *F* (ſee Fig. 3.) that takes hold of the ram *Q* by the ſtaple *R* for drawing it up. *D* is a ſpiral or fuſy fixt to the drum, on which is wound the ſmall rope *T* that goes over the pulley *U*, under the pulley *V*, and is faſtened to the top of the frame at 7. To the pulley-block *V* is hung the counterpoiſe *W*, which

which hinders the follower from accelerating as it goes down to take hold of the ram: for, as the follower tends to acquire velocity in its descent, the line *T* winds downwards upon the fusy, on a larger and larger radius, by which means the counterpoise *W* acts stronger and stronger against it; and so allows it to come down with only a moderate and uniform velocity. The bolt *Y* locks the drum to the great wheel, being pushed upward by the small lever 2, which goes through a mortise in the shaft *A*, turns upon a pin in the bar 3 fixt to the great wheel *B*, and has a weight 4, which always tends to push up the bolt *Y* through the wheel into the drum. L is the great lever turning on the axis *m*, and resting upon the forcing bar 5, 5, which goes down through a hollow in the shaft *A*, and bears upon the little lever 2.

By the horses going round, the great rope *H* is wound about the drum 6, and the ram *Q* is drawn up by the tongs *F* in the follower *G*, until the tongs comes between the inclined planes *E*; which, by shutting the tongs at the top, opens it at the foot, and discharges the ram, which falls down between the guides *b b* upon the pile *P*, and drives it by a few strokes as far into the mud as it can go; after which, the top-part is sawed off close to the mud, by an engine for that purpose. Immediately after the ram is discharged, the piece 6 upon the follower *G* takes hold of the ropes *a*,*a*, which raise the end of the lever *L*, and cause its end *N* to descend and press down the forcing bar 5 upon the little lever 2, which by pulling down the bolt *Y*, unlocks the drum *C* from the great wheel *B*; and then, the follower, being at liberty, comes down by its own weight to the ram; and the lower ends of the tongs slip

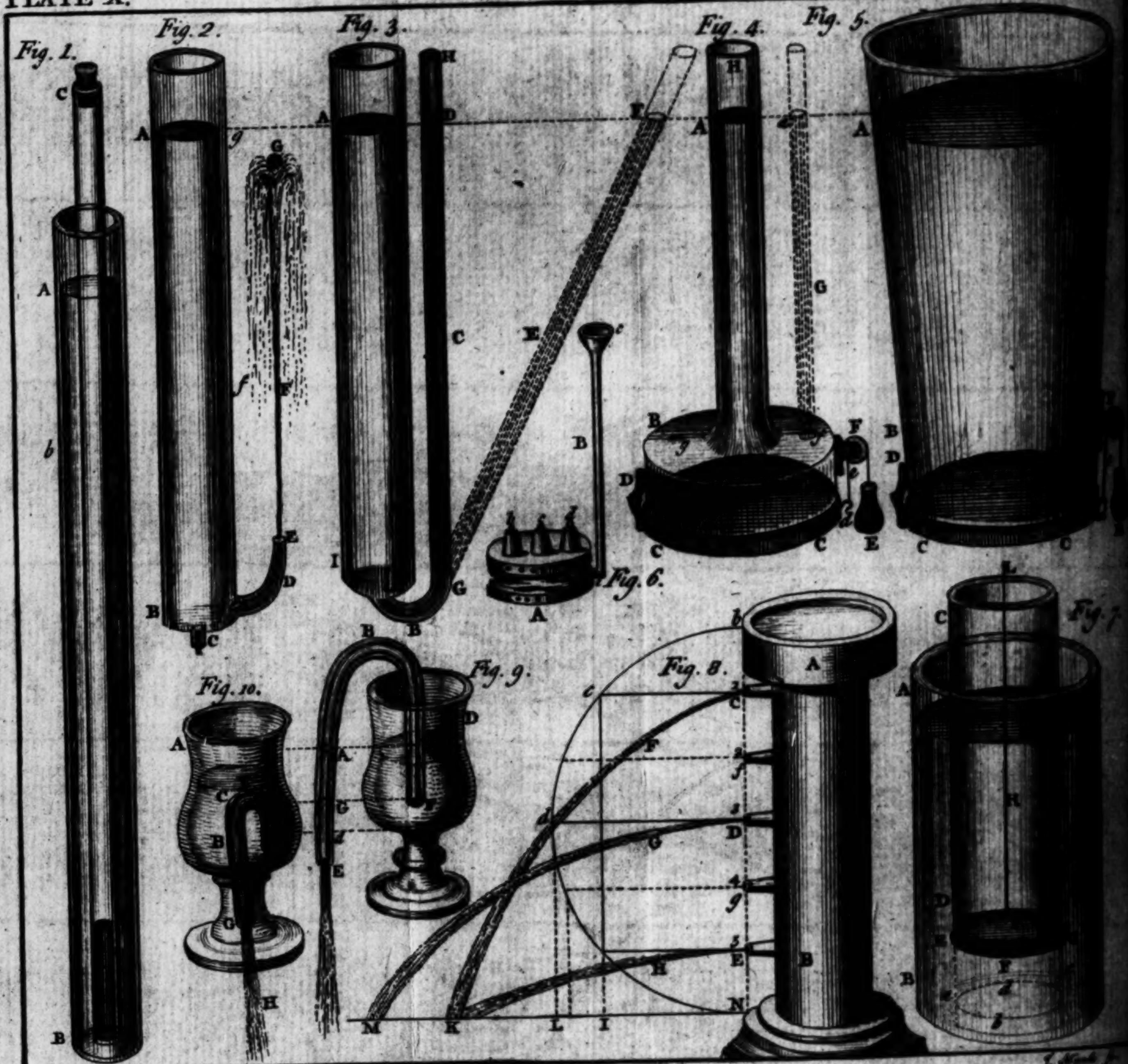
over the ſtaple *R* and the weight of their heads cauſes them to fall outward, and then ſhuts upon it. Then the weight 4 puſhes up the bolt *Y* into the drum, which locks it to the great wheel, and ſo the ram is drawn up as before.

As the follower comes down, it cauſes the drum to turn backward, and unwinds the rope from it, whilſt the horſes, great wheel, trundle and fly, go on with an uninterrupted motion; and as the drum is turning backward, the counterpoiſe *W* is drawn up, and its rope *T* winds upon the ſpiral fuſy *D*.

There are ſeveral holes in the under ſide of the drum, and the bolt *Y* always takes the firſt one that it finds when the drum ſtops by the falling of the follower upon the ram; until which ſtoppage, the bolt has not time to ſlip into any of the holes.

This engine was placed upon a barge on the water, and ſo was eaſily conveyed to any place deſired.—I never had the good fortune to ſee it, but drew this figure from a model which I made from a print of it; being not quite ſatisfied with the view which the print gives. I have been told that the ram was a ton weight, and that the guides *b b*, between which it was drawn up and let fall down, were 30 feet high. I ſuppoſe the great wheel may have had 100 cogs, and the trundle 10 ſtaves or rounds; ſo that the fly would make 10 revolutions for one of the great wheel.

PLATE X.



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LECT. V.

Of hydrostatics, and hydraulic machines, in general.

THE science of *hydrostatics* treats of the nature, gravity, pressure, and motion of fluids in general; and of weighing solids in them.

A fluid is a body that yields to the least pressure or difference of pressures. Its particles are so exceedingly small, that they cannot be discerned by the best of microscopes; they are hard, since no fluid except air or steem, can be pressed into a less space than it naturally possesses; and they are round and smooth, since they are so easily moved among one another. A definition of a fluid.

All bodies, both fluid and solid, press downwards by the force of gravity: but fluids have this wonderful property, that their pressure upwards and sidewise is equal to their pressure downwards; and this is always in proportion to their perpendicular height, without any regard to their quantity: for, as each particle is quite free to move, it will move towards that part or side on which the pressure is least. And hence, no particle or quantity of a fluid can be at rest, till it is every way equally pressed.

To shew by experiment that fluids press upward as well as downward, let *AB* be a long upright tube filled with water near to its top; and *CD* a small tube open at both ends, and immersed into the water in the large one: if the immersion be quick, you will see the water rise in the small tube to the same height that it stands in the great one, or until the surfaces of the Plate X. Fig. 1. Fluids press as much upward as downward.

water in both are on the ſame level: which ſhews that the water is preſſed upward into the ſmall tube by the weight of what is in the great one; otherwiſe it could never riſe therein, contrary to its natural gravity; unleſs the diameter of the bore were ſo ſmall, that the attraction of the tube would raiſe the water; which will never happen, if the tube be as wide as that in a common barometer. And, as the water riſes no higher in the ſmall tube than till its ſurface be on a level with the ſurface of the water in the great one, this ſhews that the preſſure is not in proportion to the quantity of water in the great tube, but in proportion to its perpendicular height therein: for there is much more water in the great tube all around the ſmall one, than what is raiſed to the ſame height in the ſmall one, as it ſtands in the great.

Take out the ſmall tube, and let the water run out of it; then it will be filled with air. Stop its upper end with the cork *C*, and it will be full of air all below the cork: this done, plunge it again to the bottom of the water in the great tube, and you will ſee the water riſe up in it to the height *E*; which ſhews that the air is a body, otherwiſe it could not hinder the water from riſing up to the ſame height as it did before, namely, to *A*; and in ſo doing, it drove the air out at the top; but now the air is confined by the cork *C*: and it alſo ſhews that the air is a compreſſible body, for if it were not ſo, a drop of water could not enter into the tube.

The preſſure of fluids being equal in all directions, it follows that the ſides of a veſſel are as much preſſed by a fluid in it, all around in any given ring of points, as the fluid below that ring is preſſed by the weight of all that ſtands above it.

it. Hence the pressure upon every point in the sides, immediately above the bottom, is equal to the pressure upon every point of the bottom. To shew this by experiment, let a hole be made at *E* in the side of the tube *AB* close by the bottom; and another hole of the same size in the bottom at *C*; then pour water into the tube, keeping it full as long as you choose the holes should run, and have two basons ready to receive the water that runs through the two holes, until you think there is enough in each bason; and you will find by measuring the quantities, that they are equal; which shews that the water run with equal speed through both holes: which it could not have done, if it had not been equally pressed through them both. For, if a hole of the same size be made in the side of the tube, as about *f*, and if all three are permitted to run together, you will find that the quantity run through the hole at *f* is much less than what has run in the same time through either of the holes *C* or *e*.

In the same figure, let the tube be re-curved from the bottom at *C* into the shape *D E*, and the hole at *C* be stopt with a cork. Then, pour water into the tube to any height, as *Ag*, and it will spout up in a jet *E F G*, nearly as high as it is kept in the tube *AB*, by continuing to pour in as much there as runs through the hole *E*; which will be the case whilst the surface *Ag* keeps at the same height. And if a little ball of cork *G* be laid upon the top of the jet, it will be supported thereby, and dance upon it. The reason why the jet rises not quite so high as the surface of the water *Ag*, is owing to the resistance it meets with in the open air: for, if a tube either great or small, was screwed upon the pipe at *E*, the

water would rise in it until the surfaces of the water in both tubes were on the same level; as will be shewn by the next experiment.

The *hydrostatic paradox.* Any quantity of a fluid, how small soever, may be made to balance and support any quantity, how great soever. This is deservedly termed *the hydrostatical paradox*, which we shall first shew by an experiment, and then account for it upon the principle above-mentioned, namely, that *the pressure of fluids is directly as their perpendicular height, without any regard to their quantity.*

Fig. 3. Let a small glass tube *D C G*, open at both ends, and bended at *B*, be joined to the end of a great one *A I* at *c d*, where the great one is also open; so that these tubes in their openings may freely communicate with each other. Then pour water through a small necked funnel into the small tube at *H*; this water will run through the joining of the tubes at *cd*, and rise up into the great tube; and if you continue pouring until the surface of the water comes to any part, as *A*, in the great tube, and then leave off, you will see that the surface of the water in the small tube will be just as high, at *D*; so that the perpendicular altitude of the water will be the same in both tubes, however small the one be in proportion to the other. This shews, that the small column *D C G* balances and supports the great column *A c d*; which it could not do if their pressures were not equal against one another in the recurved bottom at *B*.—If the small tube be made longer, and inclined in the situation *G E F*, the surface of the water in it will stand at *F*, on the same level with the surface *A* in the great tube; that is, the water will have the same perpendicular height in both tubes, although the column in the small tube is longer than that in the great one;

the

the former being oblique, and the latter perpendicular.

Since then the pressure of fluids is directly as their perpendicular heights, without any regard to their quantities, it appears that whatever the figure or size of vessels be, if they are of equal heights, and if the areas of their bottoms are equal, the pressures of equal heights of water are equal upon the bottoms of these vessels; even though the one should hold a thousand or ten thousand times as much water as would fill the other. To confirm this part of the hydrostatical paradox by an experiment, let two vessels be prepared of equal heights, but very unequal contents, such as *AB* in Fig. 4, and *AB* in Fig. 5. Let each vessel be open at both ends, and their bottoms *D d*, *D d* be of equal widths. Let a brass bottom *CC* be exactly fitted to each vessel, not to go into it, but for it to stand upon; and let a piece of wet leather be put between each vessel and its brass bottom, for the sake of closeness. Join each bottom to its vessel by a hinge *D*, so that it may open like the lid of a box; and let each bottom be kept up to its vessel by equal weights *E* and *E* hung to lines which go over the pulleys *F* and *F* (whose blocks are fixed to the sides of the vessels at *f*) and the lines tied to hooks at *d* and *d*, fixed in brass bottoms opposite to the hinges *D* and *D*. Things being thus prepared and fitted, hold the vessel *AB* (Fig. 5.) upright in your hands over a bason on a table, and cause water to be poured into the vessel slowly, till the pressure of the water bears down its bottom at the side *d*, and raises the weight *E*; and then part of the water will run out at *d*. Mark the height at which the surface *H* of the water stood in the vessel, when the bot- Fig. 4, 5.

 tom

tom began to give way at *d*; and then, holding up the other vessel *AB* (Fig. 4.) in the same manner, cause water to be poured into it at *H*; and you will see that when the water rises to *A* in this vessel, just as high as it did in the former, its bottom will also give way at *d*, and it will lose part of the water.

The natural reason of this surprising phenomenon is, that since all parts of a fluid at equal depths below the surface are equally pressed in all manner of directions, the water immediately below the fixed part *Bf* (Fig. 4.) will be pressed as much upward against its lower surface within the vessel, by the action of the column *Ag*, as it would be by a column of the same height, and of any diameter whatever; (as was evident by the experiment with the tube, Fig. 3.) and therefore, since action and reaction are equal and contrary to each other, the water immediately below the surface *Bf* will be pressed as much downward by it, as if it was immediately touched and pressed by a column of the height *gA*, and of the diameter *Bf*: and therefore, the water in the cavity *BDdf* will be pressed as much downward upon its bottom *CC*, as the bottom of the other vessel (Fig. 5.) is pressed by all the water above it.

Fig. 4. To illustrate this a little farther, let a hole be made at *f* in the fixed top *Bf*, and let a tube *G* be put into it; then, if water be poured into the tube *A*, it will (after filling the cavity *Bd*) rise up into the tube *G*, until it comes to a level with that in the tube *A*; which is manifestly owing to the pressure of the water in the tube *A*, upon that in the cavity of the vessel below it. Consequently, that part of the top *Bf*, in which the hole is now made, would, if corked up, be

pressed

pressed upward with a force equal to the weight of all the water which is supported in the tube *G*: and the same thing would hold at *g*, if a hole were made there. And so if the whole cover or top *Bf* were full of holes, and had tubes as high as the middle one *Ag* put into them, the water in each tube would rise to the same height as it is kept into the tube *A*, by pouring more into it, to make up the deficiency that it sustains by supplying the others, until they are all full: and then the water in the tube *A* would support equal heights of water in all the rest of the tubes. Or, if all the tubes except *A*, or any other one, were taken away, and a large tube equal in diameter to the whole top *Bf* were placed upon it, and cemented to it, and then if water were poured into the tube that was left in either of the holes, it would ascend through all the rest of the holes, until it filled the large tube to the same height that it stands in the small one, after a sufficient quantity had been poured into it: which shews, that the top *Bf* was pressed upward by the water under it, and before any hole was made in it, with a force equal to that wherewith it is now pressed downward by the weight of all the water above it in the great tube. And therefore, the reaction of the fixed top *Bf* must be as great, in pressing the water downward upon the bottom *CC*, as the whole pressure of the water in the great tube would have been, if the top had been taken away, and the water in that tube left to press directly upon the water in the cavity *BDdf*.

Perhaps the best machine in the world for demonstrating the upward pressure of fluids, is the hydrostatic bellows *A*; which consists of two thick oval boards, each about 16 inches broad, and 18 inches long, covered with leather, to open

Fig. 6. The *hydrostatic bellows.*

open and shut like a common bellows, but without valves; only a pipe *B*, about three feet high, is fixed into the bellows at *e*. Let some water be poured into the pipe at *c*, which will run into the bellows, and separate the boards a little. Then lay three weights *b*,*c*,*d*, each weighing 100 pounds, upon the upper board; and pour more water into the pipe *B*, which will run into the bellows, and raise up the board with all the weights upon it; and if the pipe be kept full, until the weights are raised as high as the leather which covers the bellows will allow them, the water will remain in the pipe, and support all the weights, even though it should weigh no more than a quarter of a pound, and they 300 pounds: nor will all their force be able to cause them to descend and force the water out at the top of the pipe.

The reason of this will be made evident, by considering what has been already said of the result of the pressure of fluids of equal heights without any regard to their quantity. For, if a hole be made in the upper board, and a tube be put into it, the water will rise in the tube to the same height that it does in the pipe; and would rise as high (by supplying the pipe) in as many tubes as the board could contain holes. Now, suppose only one hole to be made in any part of the board, of an equal diameter with the bore of the pipe *B*; and that the pipe holds just a quarter of a pound of water; if a person claps his finger upon the hole, and the pipe be filled with water, he will find his finger to be pressed upward with a force equal to a quarter of a pound. And as the same pressure is equal upon all equal parts of the board, each part, whose area is equal to the area of the hole, will be pressed upward with a force equal to that of a quarter of a pound: the sum

sum of all which pressures against the under side of an oval board 16 inches broad, and 18 inches long, will amount to 300 pounds; and therefore so much weight will be raised up and supported by a quarter of a pound of water in the pipe.

Hence, if a man stands upon the upper board, and blows into the bellows through the pipe *B*, he will raise himself upward upon the board: and the smaller the bore of the pipe is, the easier he will be able to raise himself. And then, by clapping his finger upon the top of the pipe, he can support himself as long as he pleases; provided the bellows be air-tight, so as not to lose what is blown into it. How a man may raise himself upward by his breath.

This figure, I confess, ought to have been much larger than any other upon the plate; but it was not thought of, until all the rest were drawn: and it could not so properly come into any other plate.

Upon this principle of the upward pressure of fluids, a piece of lead may be made to swim in water, by immersing it to a proper depth, and keeping the water from getting above it. Let *CD* be a glass tube, open at both ends, and *EFG* a flat piece of lead, exactly fitted to the lower end of the tube, not to go within it, but for it to stand upon; with a wet leather between the lead and the tube to make close work. Let this leaden bottom be half an inch thick, and held close to the tube by pulling the packthread *IHL* upward at *L* with one hand, whilst the tube is held in the other by the upper end *C*. In this situation, let the tube be immersed in water in the glass vessel *AB*, to the depth of six inches below the surface of the water at *K*; and then, the leaden bottom *EFG* will be plunged to the depth of somewhat more than eleven times its How lead may be made to swim in water. Fig. 7.

its own thickness: holding the tube at that depth, you may let go the thread at *L*; and the lead will not fall from the tube, but will be kept to it by the upward pressure of the water below it occasioned by the height of the water at *K* above the level of the lead. For as lead is 11.33 times as heavy as its bulk of water, and is in this experiment immersed to a depth somewhat more than 11.33 times its thickness, and no water getting into the tube between it and the lead, the column of water *E a b c G* below the lead is pressed upward against it by the water *K D E G L* all around the tube; which water being a little more than 11.33 times as high as the lead is thick, is sufficient to balance and support the lead at the depth *K E*. If a little water be poured into the tube upon the lead, it will increase the weight upon the column of water under the lead, and cause the lead to fall from the tube to the bottom of the glass vessel, where it will lie in the situation *b d*. Or, if the tube be raised a little in the water, the lead will fall by its own weight, which will then be too great for the pressure of the water around the tube upon the column of water below it.

How light wood may be made to lie at the bottom of water.

Let two pieces of wood be plained quite flat, so as no water may get in between them when they are put together: let one of the pieces, as *b d*, be cemented to the bottom of the vessel *AB* (Fig. 7.) and the other piece be laid flat and close upon it, and held down to it by a stick, whilst water is poured into the vessel; then remove the stick, and the upper piece of wood will not rise from the lower one: for, as the upper one is pressed down both by its own weight and the weight of all the water over it, whilst the contrary pressure of the water is kept off by the wood

wood under it, it will lie as ſtill as a ſtone would do in its place. But if it be raiſed ever ſo little at any edge, ſome water will then get under it; which being acted upon by the water above, will immediately preſs it upward; and as it is lighter than its bulk of water, it will riſe, and float upon the ſurface of the water.

All fluids weigh juſt as much in their own element as they do in open air. To prove this by experiment, let as much ſhot be put into a phial, as, when corked, will make it ſink in water: and being thus charged, let it be weighed, firſt in air, and then in water, and the weights in both caſes wrote down. Then, as the phial hangs ſuſpended in water, and counterpoiſed, pull out the cork, that water may run into it, and it will deſcend, and pull down that end of the beam. This done, put as much weight into the oppoſite ſcale as will reſtore the equipoiſe; which weight will be found to anſwer exactly to the additional weight of the phial when it is again weighed in air, with the water in it.

The velocity with which water ſpouts out at a hole in the ſide or bottom of a veſſel, is as the * ſquare root of the depth or diſtance of the hole below the ſurface of the water. For, in order to make double the quantity of a fluid run through one hole as through another of the ſame ſize, it will require four times the preſſure of the other, and therefore muſt be four times the depth of the other below the ſurface of the water: and for the ſame reaſon, three times the quantity running in an equal time through the ſame

The velocity of ſpouting water.

* The ſquare root of any number is that which being multiplied by itſelf produces the ſaid number. Thus, 2 is the ſquare root of 4, and 3 is the ſquare root of 9: for 2 multiplied by 2 produces 4, and 3 multiplied by 3 produces 9, &c.

ſame ſort of hole, muſt run with three times the velocity, which will require nine times the preſſure; and conſequently muſt be nine times as deep below the ſurface of the fluid: and ſo on.—To prove this by an experiment, let two pipes, as *C* and *g*, of equal ſized bores, be fixed into the ſide of the veſſel *AB*; the pipe *g* being four times as deep below the ſurface of the water at *b* in the veſſel as the pipe *C* is: and whilſt theſe pipes run, let water be conſtantly poured into the veſſel, to keep the ſurface ſtill at the ſame height. Then, if a cup that holds a pint be ſo placed as to receive the water that ſpouts from the pipe *C*, and at the ſame moment a cup that holds a quart be ſo placed as to receive the water that ſpouts from the pipe *g*, both cups will be filled at the ſame time by their reſpective pipes.

Fig. 8.

The horizontal diſtance to which water will ſpout from pipes.

The horizontal diſtance, to which a fluid will ſpout from a horizontal pipe, in any part of the ſide of an upright veſſel below the ſurface of the fluid, is equal to twice the length of a perpendicular to the ſide of the veſſel, drawn from the mouth of the pipe to a ſemicircle deſcribed upon the altitude of the fluid: and therefore, the fluid will ſpout to the greateſt diſtance poſſible from a pipe, whoſe mouth is at the center of the ſemicircle; becauſe a perpendicular to its diameter (ſuppoſed parallel to the ſide of the veſſel) drawn from that point, is the longeſt that can poſſibly be drawn from any part of the diameter to the circumference of the ſemicircle. Thus, if the veſſel *AB* be full of water, the horizontal pipe *D* be in the middle of its ſide, and the ſemicircle *Nedcb* be deſcribed upon *D* as a center, with the radius or ſemidiameter *DgN*, or *Dfb*, the perpendicular *Dd* to the diameter *NDb* is the longeſt that can be drawn from

Fig. 8.

from any part of the diameter to the circumference $Nedcb$. And if the veſſel be kept full, the jet G will ſpout from the pipe D, to the horizontal diſtance NM, which is double the length of the perpendicular Dd. If two other pipes, as C and E, be fixed into the ſide of the veſſel at equal diſtances above and below the pipe D, the perpendiculars Cc and Ee, from theſe pipes to the ſemicircle, will be equal; and the jets F and H ſpouting from them will each go to the horizontal diſtance NK; which is double the length of either of the equal perpendiculars Cc or Dd.

Fluids by their preſſure may be conveyed over hills and vallies in bended pipes, to any height not greater than the level of the ſprings from whence they flow. But when they are deſigned to be raiſed higher than the ſprings, forcing engines muſt be uſed; which ſhall be deſcribed when we come to treat of pumps. **How water may be conveyed over hills and valleys.**

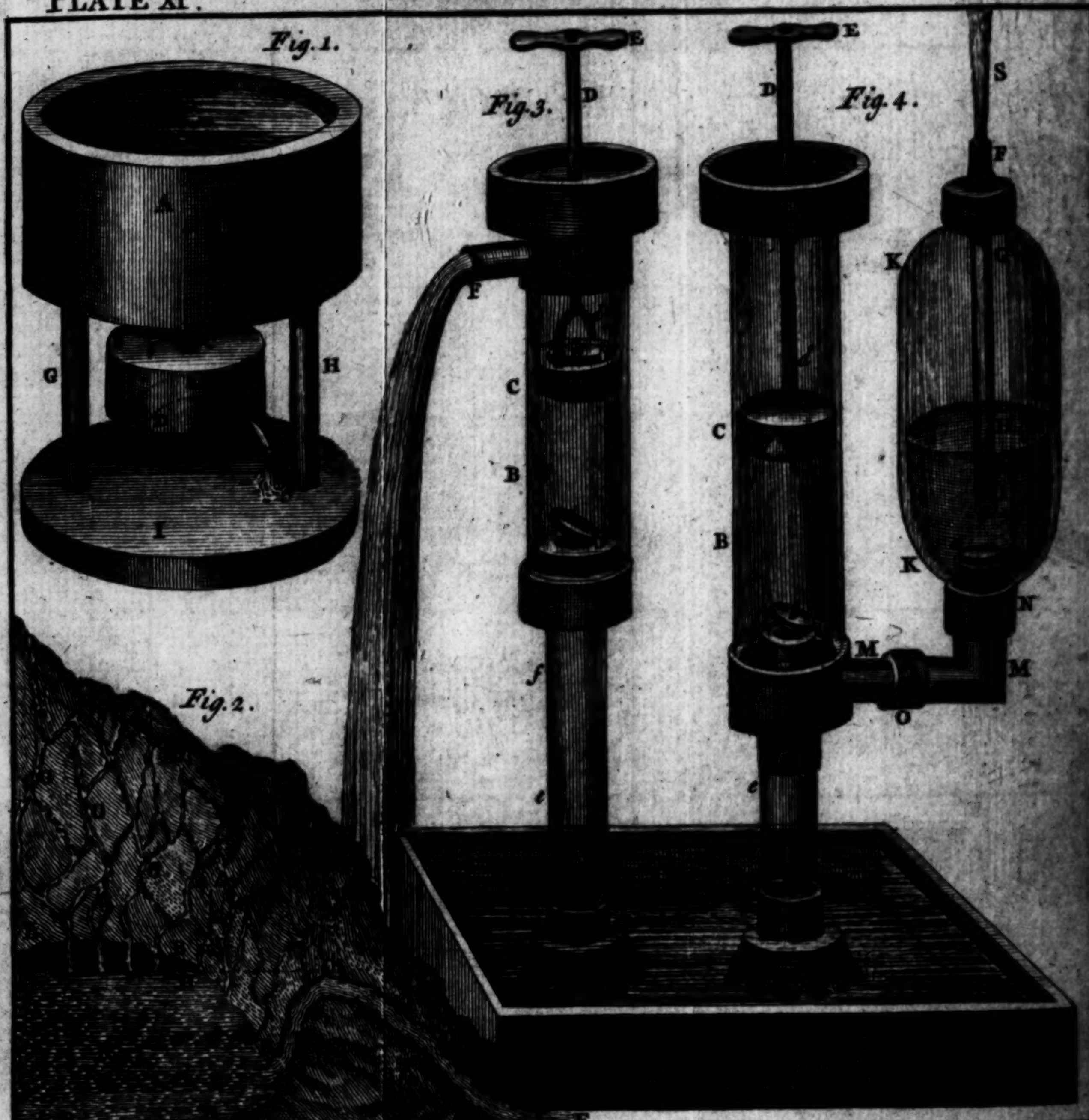
A *ſyphon*, generally uſed for decanting liquors, is a bended pipe, whoſe legs are of unequal lengths; and the ſhorteſt leg muſt always be put into the liquor intended to be decanted, that the perpendicular altitude of the column of liquor in the other leg may be longer than the column in the immerſed leg, eſpecially above the ſurface of the water. For, if both columns were equally high in that reſpect, the atmoſphere, which preſſes as much upward as downward, and therefore acts as much upward againſt the column in the leg that hangs without the veſſel, as it acts downward upon the ſurface of the liquor in the veſſel, would hinder the running of the liquor through the ſyphon, even though it were brought over the bended part by ſuction. So that there is nothing left to cauſe

caufe the motion of the liquor, but the fuperior weight of the column, in the longer leg, on account of its having the greater perpendicular height.

Fig. 9. Let *D* be a cup filled with water to *C*, and *ABC* a fyphon, whofe fhorter leg *BCF* is immerfed in the water from *C* to *F*. If the end of the other leg were no lower than the line *AC*, which is level with the furface of the water, the fyphon would not run, even though the air fhould be drawn out of it at the mouth *A*. For although the fuction would draw fome water at firft, yet the water would ftop at the moment the fuction ceafed; becaufe the air would act as much upward againft the water at *A*, as it acted downward for it by preffing on the furface at *C*. But if the leg *AB* comes down to *G*, and the air be drawn out at *G* by fuction, the water will immediately follow, and continue to run, until the furface of the water in the cup comes down to *F*; becaufe, till then, the perpendicular height of the column *BAG* will be greater than that of the column *CB*; and confequently, its weight will be greater, until the furface comes down to *F*; and then the fyphon will ftop, though the leg *CF* fhould reach to the bottom of the cup. For which reafon, the leg that hangs without the cup is always made long enough to reach below the level of its bottom, as from *d* to *E*: and then, when the fyphon is emptied of air by fuction at *E*, the water immediately follows, and by its continuity brings away the whole from the cup; juft as pulling one end of a thread will make the whole clue follow.

If the perpendicular height of a fyphon, from the furface of the water to its bended top at *B*,

PLATE XI.



J. Ferguson delin.   J. Mynde sc.

be more than 33 feet, it will draw no water, even though the other leg were much longer, and the syphon quite emptied of air; because the weight of a column of water 33 feet high is equal to the weight of as thick a column of air, reaching from the surface of the earth to the top of the atmosphere; so that there will then be an equilibrium, and consequently, though there would be weight enough of air upon the surface *C* to make the water ascend in the leg *C B* almost to the height *B*, if the syphon were emptied of air, yet the weight would not be sufficient to force the water over the bend; and therefore, it could never be brought into the leg *B A G*.

Let a hole be made quite through the bottom of the cup *A*, and the longer leg of the bended syphon *D E B G* be cemented into the hole, so that the end *D* of the shorter leg *D E* may almost touch the bottom of the cup within. Then, if water be poured into this cup, it will rise in the shorter leg by its upward pressure, extruding the air all the way before it through the longer leg: and when the cup is filled above the bend of the syphon at *F*, the pressure of the water in the cup will force it over the bend of the syphon; and it will descend in the longer leg *C B G*, and run through the bottom, until the cup be emptied.

Fig. 10. *Tantalus's cup.*

This is generally called *Tantalus's cup*, and the legs of the syphon in it are almost close together; and a little hollow statue, or figure of a man, is sometimes put over the syphon to conceal it; the bend *E* being within the neck of the figure as high as the chin. So that poor thirsty *Tantalus* stands up to the chin in water, imagining it will rise a little higher, and he

I may

may drink; but instead of that, when the water comes up to his chin, it immediately begins to descend, and so, as he cannot stoop to follow it, he is left as much pained with thirst as ever.

The fountain at command. Plate XI. Fig. 1.

The device called *the fountain at command* acts upon the same principle with the syphon in the cup. Let two vessels *A* and *B* be joined together by the pipe *C* which opens into them both. Let *A* be open at top, *B* close both at top and bottom (save only a small hole at *b* to let the air get out of the vessel *B*) and *A* be of such a size, as to hold about six times as much water as *B*. Let a syphon *D E F* be soldered to the vessel *D*, so that the part *D E e* may be within the vessel, and *F* without it; the end *D* almost touching the bottom of the vessel, and the end *F* below the level of *D*: the vessel *B* hanging to *A* by the pipe *C* (soldered into both) and the whole supported by the pillars *G* and *H* upon the stand *I*. The bore of the pipe must be considerably less than the bore of the syphon.

The whole being thus constructed, let the vessel *A* be filled with water, which will run through the pipe *C*, and fill the vessel *B*. When *B* is filled above the top of the syphon at *E*, the water will run through the syphon, and be discharged at *F*. But as the bore of the syphon is larger than the bore of the pipe, the syphon will run faster than the pipe, and will soon empty the vessel *B*; upon which the water will cease from running through the syphon at *F*, until the pipe *C* re-fills the vessel *B*, and then it will begin to run as before. And thus the syphon will continue to run and stop alternately, until all the water in the vessel *A* has run through

through the pipe *C.*—So that after a few trials, one may easily guess about what time the syphon will stop, and when it will begin to run: and then, to amuse others, he may call out *stop*, or *run*, accordingly.

Upon this principle, we may easily account for *intermitting* or *reciprocating springs.* Let *AA* be part of a hill, within which there is a cavity *BB*; and from this cavity a vein or channel running in the direction *BCDE.* The rain that falls upon the side of the hill will sink and strain through the small pores and cranies *G, G, G, G*; and fill the cavity with water *K.* When the water rises to the level *HHC*, the vein *BCDE* will be filled to *C*, and the water will run through *CDF* as through a syphon; which running will continue until the cavity be emptied, and then it will stop until the cavity be filled again. *Intermitting springs.* Fig. 2.

The *common sucking pump*, with which we draw water out of wells, is an engine both pneumatic and hydraulic. It consists of a pipe open at both ends, in which is a moveable piston, bucket, or sucker, as big as the bore of the pipe in that part wherein it works; and is leathered round, so as to fit the bore exactly; and may be moved up and down, without suffering any air to come between it and the pipe or pump barrel. The *common pump.*

We shall explain the construction both of this and the forcing-pump by pictures of glass models in which, both the action of the pistons and motion of the valves are seen.

Hold the model *DCBL* upright in the vessel of water *K*, the water being deep enough to rise at least as high as from *A* to *L.* The valve *a* on the moveable bucket *G*, and the valve *b* Fig. 3.

on the fixed box *H*, (which box quite fills the bore of the pipe or barrel at *H*) will each lie close, by its own weight, upon the hole in the bucket and box, until the engine begins to work. The valves are made of brass, and covered underneath with leather for closing the holes the more exactly: and the bucket *G* is raised and depressed alternately by the handle *E* and rod *D d*, the bucket being supposed at *B* before the working begins.

Take hold of the handle *E*, and thereby draw up the bucket from *B* to *C*, which will make room for the air in the pump all the way below the bucket to dilate itself, by which its spring is weakened, and then its force is not equivalent to the weight or pressure of the outward air upon the water in the vessel *K*: and therefore, at the first stroke, the outward air will press up the water through the notched foot *A*, into the lower pipe, about as far as *e*: this will condense the rarefied air in the pipe between *e* and *C* to the same state it was in before; and then, as its spring within the pipe is equal to the force or pressure of the outward air, the water will rise no higher by the first stroke; and the valve *b*, which was raised a little by the dilation of the air in the pipe, will fall, and stop the hole in the box *H*; and the surface of the water will stand at *e*. Then depress the piston or bucket from *C* to *B*, and as the air in the part *B* cannot get back again through the valve *b*, it will (as the bucket descends) raise the valve *a*, and so make its way through the upper part of the barrel *d* into the open air. But upon raising the bucket *G* a second time, the air between it and the water in the lower pipe at *a* will be again left at liberty to

fill

fill a larger ſpace; and ſo its ſpring being again weakened, the preſſure of the outward air on the water in the veſſel *K* will force more water up into the lower pipe from *e* to *f*; and when the bucket is at its greateſt height *C*, the lower valve *b* will fall, and ſtop the hole in the box *H* as before. At the next ſtroke of the bucket or piſton, the water will riſe through the box *H* towards *B*, and then the valve *b*, which was raiſed by it, will fall when the bucket *G* is at its greateſt height. Upon depreſſing the bucket again, the water cannot be puſhed back through the valve *b*, which keeps cloſe upon the hole whilſt the piſton deſcends. And upon raiſing the piſton again, the outward preſſure of the air will force the water up through *H*, where it will raiſe the valve, and follow the bucket to *C*. Upon the next depreſſion of the bucket *G*, it will go down into the water in the barrel *B*; and as the water cannot be driven back through the now cloſe valve *b*, it will raiſe the valve *a* as the bucket deſcends, and will be lifted up by the bucket when it is next raiſed. And now, the whole ſpace below the bucket being full, the water above it cannot ſink when it is next depreſſed; but upon its depreſſion, the valve *a* will riſe to let the bucket go down; and when it is quite down, the valve *a* will fall by its weight, and ſtop the hole in the bucket. When the bucket is next raiſed, all the water above it will be lifted up, and begin to run off by the pipe *F*. And thus, by raiſing and depreſſing the bucket alternately, there is ſtill more water raiſed by it; which getting above the pipe *F*, into the wide top *I*, will ſupply the pipe, and make it run with a continued ſtream.

So, at every time the bucket is raiſed, the valve *b* riſes, and the valve *a* falls; and at every time the bucket is depreſſed, the valve *b* falls, and *a* riſes.

As it is the preſſure of the air or atmoſphere which cauſes the water to riſe, and follow the piſton or bucket *G* as it is drawn up; and ſince a column of water 33 feet high is of equal weight with as thick a column of the atmoſphere, from the earth to the very top of the air; therefore, the perpendicular height of the piſton or bucket from the ſurface of the water in the well muſt always be leſs than 33 feet; otherwiſe the water will never get above the bucket. But, when the height is leſs, the preſſure of the atmoſphere will be greater than the weight of the water in the pump, and will therefore raiſe it above the bucket: and when the water has once got above the bucket, it may be lifted thereby to any height, if the rod *D* be made long enough, and a ſufficient degree of ſtrength be employed, to raiſe it with the weight of the water above the bucket.

The force required to work a pump, will be as the height to which the water is raiſed, and as the ſquare of the diameter of the pump-bore, in that part where the piſton works. So that, if two pumps be of equal heights, and one of them be twice as wide in the bore as the other, the wideſt will raiſe four times as much water as the narroweſt; and will therefore require four times as much ſtrength to work it.

The wideneſs or narrowneſs of the pump, in any other part beſides that in which the piſton works, does not make the pump either more or leſs difficult to work, except what difference may ariſe from the friction of the water in the bore;

bore; which is always greater in a narrow bore than in a wide one, because of the greater velocity of the water.

The pump-rod is never raised directly by such a handle as *E* at the top, but by means of a lever, whose longer arm (at the end of which the power is applied) generally exceeds the length of the shorter arm five or six times; and, by that means, it gives five or six times as much advantage to the power. Upon these principles, it will be easy to find the dimensions of a pump that shall work with a given force, and draw water from any given depth. But, as these calculations have been generally neglected by pump-makers (either for want of skill or industry) the following table was calculated by the late ingenious Mr. *Booth* for their benefit *. In this calculation, he supposed the handle of the pump to be a lever increasing the power five times; and had often found that a man can work a pump four inches diameter, and 30 feet high, and discharge $27\frac{1}{2}$ gallons of water (English wine measure) in a minute. Now, if it be required to find the diameter of a pump, that shall raise water with the same ease from any other height above the surface of the *well*; look for that height in the first column, and over-against it in the second you have the diameter or width of the pump; and in the third, you find the quantity of water which a man of ordinary strength can discharge in a minute.

* I have taken the liberty to make a few alterations in Mr. *Booth*'s numbers in the table, and to lengthen it out from 80 feet to 100.

Height of the pump above the surface of the *well.*	Diameter of the bore where the bucket works.		Water discharged in a minute, English wine measure.	
Feet.	Inches.	100 parts.	Gallons.	Pints.
10	6	.93	81	6
15	5	.66	54	4
20	4	.90	40	7
25	4	.38	32	6
30	4	.00	27	2
35	3	.70	23	3
40	3	.46	20	3
45	3	.27	18	1
50	3	.10	16	3
55	2	.95	14	7
60	2	.84	13	5
65	2	.72	12	4
70	2	.62	11	5
75	2	.53	10	7
80	2	.45	10	2
85	2	.38	9	5
90	2	.31	9	1
95	2	.25	8	5
100	2	.19	8	1

Fig. 4. The *forcing-pump.*

The *forcing-pump* raises water through the box *H* in the same manner as the sucking-pump does, when the plunger or piston *g* is lifted up by the rod *D d*. But this plunger has no hole through it, to let the water in the barrel *BC* get above it, when it is depressed to *B*, and the valve *b* (which rose by the ascent of the water

water through the box *H* when the plunger *g* was drawn up) falls down and ſtops the hole in *H*, the moment that the plunger is raiſed to its greateſt height. Therefore, as the water between the plunger *g* and box *H* can neither get through the plunger upon its deſcent, nor back again into the lower part of the pump *L e*, but has a free paſſage by the cavity around *H* into the pipe *M M*; which opens into the air-veſſel *KK* at *P*; the water is forced through the pipe *MM* by the decent of the plunger, and driven into the air-veſſel; and in running up through the pipe at *P*, it opens the valve *a*; which ſhuts at the moment the plunger begins to be raiſed, becauſe the action of the water againſt the under ſide of the valve then ceaſes.

The water, being thus forced into the air-veſſel *K K* by repeated ſtrokes of the plunger, gets above the lower end of the pipe *G H I*, and then begins to condenſe the air in the veſſel *KK*. For, as the pipe *G H* is fixed air-tight into the veſſel below *F*, and the air has no way to get out of the veſſel but through the mouth of the pipe at *I*, and cannot get out when the mouth *I* is covered with water, and is more and more condenſed as the water riſes upon the pipe, the air then begins to act forcibly by its ſpring againſt the ſurface of the water at *H*: and this action drives the water up through the pipe *I H G F*, from whence it ſpouts in a jet *S* to a great height; and is ſupplied by alternately raiſing and depreſſing of the plunger *g*, which conſtantly forces the water that it raiſes through the valve *H*, along the pipe *M M*, into the air-veſſel *K K*.

The higher that the ſurface of the water *H* is raiſed in the air-veſſel, the leſs ſpace will the air

air be condensed into, which before filled the vessel; and therefore the force of its spring will be so much the stronger upon the water, and will drive it with the greater force through the pipe at *F:* and as the spring of the air continues whilst the plunger *g* is rising, the stream or jet *S* will be uniform, as long as the action of the plunger continues: and when the valve *b* opens, to let the water follow the plunger upward, the valve *a* shuts, to hinder the water, which is forced into the air vessel, from running back by the pipe *MM* into the barrel of the pump.

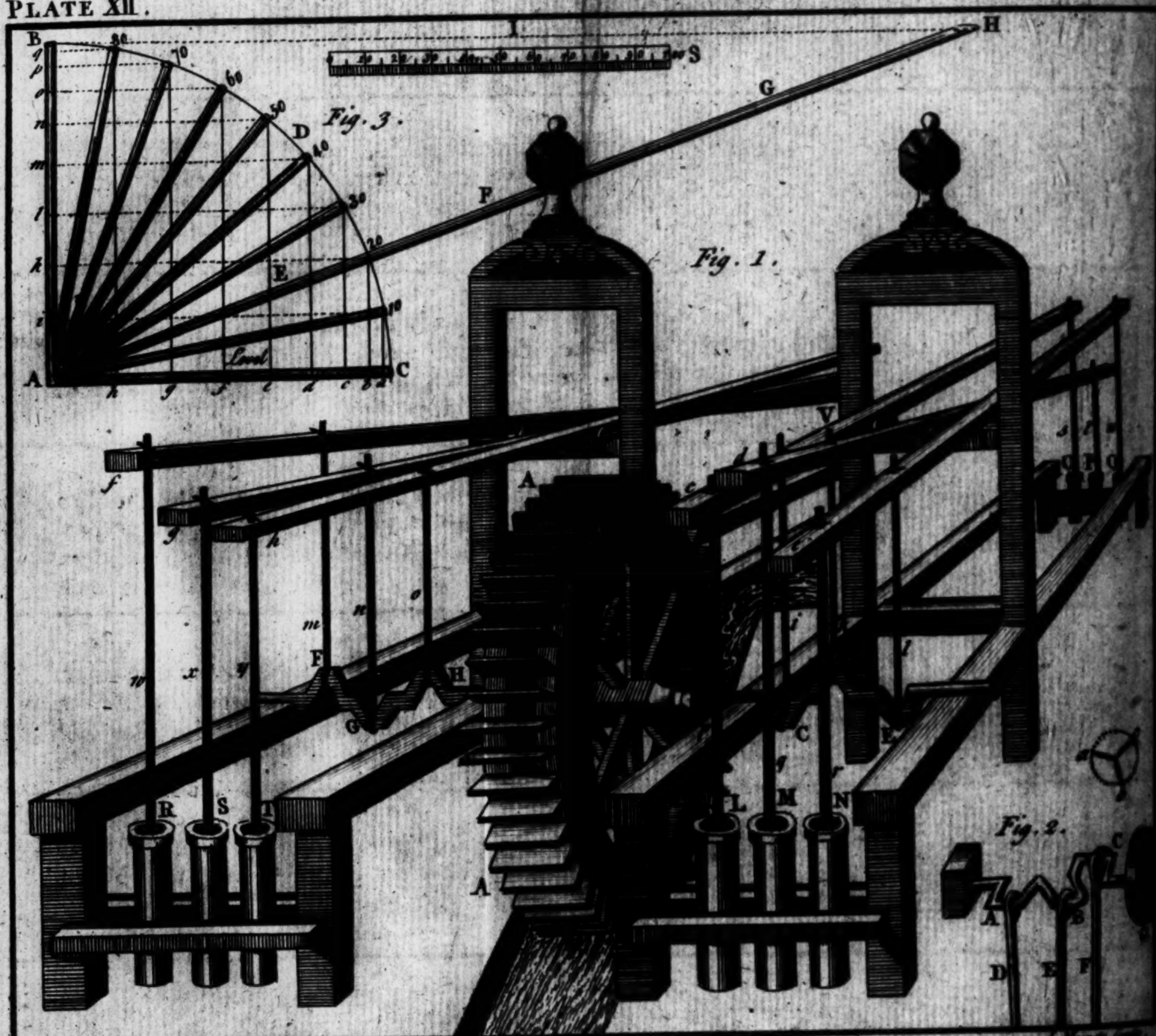
If there was no air-vessel to this engine, the pipe *GHI* would be joined to the pipe *MMN* at *P*; and then, the jet *S* would stop every time the plunger is raised, and run only when the plunger is depressed.

Mr. *Newsham*'s water-engine, for extinguishing fire, consists of two forcing-pumps, which alternately drive water into a close vessel of air; and by forcing the water into that vessel, the air in it is thereby condensed, and compresses the water so strongly, that it rushes out with great impetuosity and force through a pipe that comes down into it; and makes a continued uniform stream by the condensation of the air upon its surface in the vessel.

By means of forcing-pumps, water may be raised to any height above the level of a river or spring; and machines may be contrived to work these pumps, either by a running stream, a fall of water, or by horses. An instance in each sort will be sufficient to shew the method.

First,

PLATE XII.



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First, by a running ſtream, or a fall of water. Let *AA* be a wheel, turned by the fall of water *B B*; and have any number of cranks (ſuppoſe ſix) as *C*, *D*, *E*, *F*, *G*, *H*, on its axis, according to the ſtrength of the fall of water, and the height to which the water is intended to be raiſed by the engine. As the wheel turns round, theſe cranks move the levers *c*, *d*, *e*, *f*, *g*, *h* up and down, by the iron rods *i*, *k*, *l*, *m*, *n*, *o*; which alternately raiſe and depreſs the piſtons by the other iron rods *p*, *q*, *r*, *ſ*, *t*, *u*, *w*, *x*, *y*, in twelve pumps; nine whereof, as *L*, *M*, *N*, *O*, *P*, *Q*, *R*, *S*, *T*, appear in the plate; the other three being hid behind the work at *V*. And as pipes may go from all theſe pumps, to convey the water (drawn up by them to a ſmall height) into a cloſe ciſtern, from which the main pipe proceeds, the water will be forced into this ciſtern by the deſcent of the piſtons. And as each pipe, going from its reſpective pump into the ciſtern, has a valve at its end in the ciſtern, theſe valves will hinder the return of the water by the pipes; and therefore, when the ciſtern is once full, each piſton upon its deſcent will force the water (conveyed into the ciſtern by a former ſtroke) up the main pipe, to the height the engine was intended to raiſe it: which height depends upon the quantity raiſed, and the power that turns the wheel. When the power upon the wheel is leſſened by any defect of the quantity of water turning it, a proportionable number of the pumps may be laid aſide, by diſengaging their rods from the vibrating levers.

Plate XII. Fig. 1.

A pump engine to go by water.

This figure is a repreſentation of the engine erected at *Blenheim* for the Duke of *Marlborough*, by the late ingenious Mr. *Alderſea*. The water-wheel

wheel is $7\frac{1}{2}$ feet in diameter, according to Mr. *Switzer*'s account in his Hydraulics.

When ſuch a machine is placed in a ſtream that runs upon a ſmall declivity, the motion of the levers and action of the pumps will be but ſlow; ſince the wheel muſt go once round for each ſtroke of the pumps. But, when there is a large body of ſlow running water, a cog or ſpur-wheel may be placed upon each ſide of the water-wheel *A A*, upon its axis, to turn a trundle upon each ſide; the cranks being upon the axis of the trundle. And by proportioning the cog-wheels to the trundles, the motion of the pumps may be made quicker, according to the quantity and ſtrength of the water upon the firſt wheel; which may be as great as the workman pleaſes; according to the length and breadth of the float-boards or wings of the wheel. In this manner, the engine for raiſing water at *London-Bridge* is conſtructed; in which, the water-wheel is 20 feet diameter, and the floats 14 feet long.

A pump-engine to go by horſes.

Fig. 2.

Where a ſtream or fall of water cannot be had, and gentlemen want to have water raiſed, and brought to their houſes from a rivulet or ſpring; this may be effected by a horſe-engine, working three forcing-pumps which ſtand in a reſervoir filled by the ſpring or rivulet: the piſtons being moved up and down in the pumps by means of a triple crank *ABC*, which, as it is turned round by the trundle *G*, raiſes and depreſſes the rods *D*,*E*,*F*. The trundle may be turned by ſuch a wheel as *F* in Fig. 1. of Plate VIII, having levers *y*,*y*,*y*,*y*, on its upright axle, to which horſes may be joined for working the engine. And if the wheel has three times as many cogs as the trundle has ſtaves or rounds, the trundle and cranks will make three revolutions for every one

of

of the wheel: and as each crank will fetch a ſtroke in the time it goes round, the three cranks will make nine ſtrokes for every turn of the great wheel.

The cranks ſhould be made of caſt iron, becauſe *that* will not bend; and they ſhould each make an angle of 120 with both of the others, as at *a,b,c*; which is (as it were) a view of their *radii*, in looking endwiſe at the axis: and then there will be always one or other of them going downward, which will puſh the water forward with a continued ſtream into the main pipe. For, when *b* is almoſt at its loweſt ſituation, and is therefore juſt beginning to loſe its action upon the piſton which it moves, *c* is beginning to move downward, which will by its piſton continue the propelling force upon the water: and when *c* is come down to the poſition of *b*, *a* will be in the poſition of *c*. Plate XII. Fig. 2.

The more perpendicularly the piſton-rods move up and down in the pumps, the freer and better will their ſtrokes be: but a little deviation from the perpendicular will not be material. Therefore, when the pump-rods *D*, *E*, and *F* go down into a deep well, they may be moved directly by the cranks, as is done in a very good horſe-engine of this ſort at the late Sir *James Creed*'s at *Greenwich*, which forces up water about 64 feet from a well under ground, to a reſervoir on the top of his houſe. But when the cranks are only at a ſmall height above the pumps, the piſtons muſt be moved by vibrating levers, as in the above engine at *Blenheim*: and the longer the levers are, the nearer will the ſtrokes be to a perpendicular.

Let us ſuppoſe, that in ſuch an engine as Sir *James Creed*'s, the great wheel is 12 feet diameter, the trundle 4 feet, and the radius or length of

A calculation of the quantity

of water that may be raised by a horse-engine.

of each crank 9 inches, working a piston in its pump. Let there be three pumps in all, and the bore of each pump be four inches diameter. Then, if the great wheel has three times as many cogs as the trundle has staves, the trundle and cranks will go three times round for each revolution of the horses and wheel, and the three cranks will make nine strokes of the pumps in that time, each stroke being 18 inches (or double the length of the crank) in a four-inch bore. Let the diameter of the horse-walk be 18 feet, and the perpendicular height to which the water is raised above the surface of the well be 64 feet.

If the horses go at the rate of two miles an hour (which is very moderate walking) they will turn the great wheel 187 times round in an hour.

In each turn of the wheel the pistons make 9 strokes in the pumps, which amount to 1683 in an hour.

Each stroke raises a column of water 18 inches long, and four inches thick, in the pump-barrels; which column, upon the descent of the piston, is forced into the main pipe, whose perpendicular altitude above the surface of the well is 64 feet.

Now, since a column of water 18 inches long, and 4 inches thick, contains 226.18 cubic inches, this number multiplied by 1683 (the strokes in an hour) gives 380661 for the number of cubic inches of water raised in an hour.

A gallon, in wine measure, contains 231 cubic inches, by which divide 380661, and it quotes 1468 in round numbers, for the number of gallons raised in an hour; which, divided by 63, gives $26\frac{1}{4}$ hogsheads.—If the horses go faster, the quantity raised will be so much the greater.

In this calculation it is supposed that no water is

is wasted by the engine. But as no forcing engine can be supposed to lose less than a fifth part of the calculated quantity of water, between the pistons and barrels, and by the opening and shutting of the valves, the horses ought to walk almost $2\frac{1}{2}$ miles *per* hour, to fetch up this loss.

A column of water 4 inches thick, and 64 feet high, weighs $349\frac{9}{16}$ pounds averdupoise, or $424\frac{5}{12}$ pounds troy; and this weight together with the friction of the engine, is the resistance that must be overcome by the strength of the horses.

The horse-tackle should be so contrived, that the horses may rather push on than drag the levers after them. For if they draw, in going round the walk, the outside leather straps will rub against their sides and hams; which will hinder them from drawing at right angles to the levers, and so make them pull at a disadvantage. But if they push the levers before their breasts, instead of dragging them, they can always walk at right angles to these levers.

It is no ways material what the diameter of the main or conduct pipe be: for the whole resistance of the water therein, against the horses will be according to the height to which it is raised, and the diameter of that part of the pump in which the piston works, as we have already observed. So that by the same pump, an equal quantity of water may be raised in (and consequently made to run from) a pipe of a foot diameter, with the some ease as in a pipe of five or six inches; or rather with more ease, because its velocity in a large pipe will be less than in a small one; and therefore its friction against the sides of the pipe will be less also.

And the force required to raise water depends not upon the length of the pipe, but upon the perpendicular height to which it is raised therein

above

above the level of the ſpring. So that the ſame force, which would raiſe water to the height *AB* in the upright pipe *Aiklmnopq B*, will raiſe it to the ſame height or level *B I H* in the oblique pipe *AEFGH.* For the preſſure of the water at the end *A* of the latter, is no more than its preſſure againſt the end *A* of the former.

Fig. 3.

The weight or preſſure of water at the lower end of the pipe, is always as the ſine of the angle to which the pipe is elevated above the level parallel to the horizon. For, although the water in the upright pipe *AB* would require a force applied immediately to the lower end *A* equal to the weight of all the water in it, to ſupport the water, and a little more to drive it up, and out of the pipe; yet, if that pipe be inclined from its upright poſition to an angle of 80 degrees (as in *A* 80) the force required to ſupport or to raiſe the ſame cylinder of water will then be as much leſs, as the ſine 80 *b* is leſs than the radius *AB*; or as the ſine of 80 degrees is leſs than the ſine of 90. And ſo, decreaſing as the ſine of the angle of elevation leſſens, until it arrives at its level *AC* or place of reſt, where the force of the water is nothing at either end of the pipe. For, although the abſolute weight of the water is the ſame in all poſitions, yet its preſſure at the lower end decreaſes, as the ſine of the angle of elevation decreaſes; as will appear plainly by a farther conſideration of the figure.

Let two pipes, *AB* and *AC*, of equal lengths and bores, join each other at *A*; and let the pipe *AB* be divided into 100 equal parts, as the ſcale *S* is; whoſe length is equal to the length of the pipe.—Upon this length, as a radius, deſcribe the quadrant *B D C*, and divide it into 90 equal parts or degrees.

Let the pipe *AC* be elevated to 10 degrees

upon the quadrant, and filled with water; then, part of the water that is in it will riſe in the pipe *A B*, and if it be kept full of water, it will raiſe the water in the pipe *A B* from *A* to *i*; that is, to a level *i* 10 with the mouth of the pipe at 10: and the upright line *a* 10, equal to *Ai*, will be the ſine of 10 degrees elevation; which being meaſured upon the ſcale *S*, will be about 17.4 of ſuch parts as the pipe contains 100 in length: and therefore, the force or preſſure of the water at *A*, in the pipe *A* 10, will be to the force or preſſure at *A* in the pipe *AB*, as 17.3 to 100.

Let the ſame pipe be elevated to 20 degrees in the quadrant, and if it be kept full of water, part of that water will run into the pipe *A B*, and riſe therein to the height *A k*, which is equal to the length of the upright line *b* 20, or to the ſine of 20 degrees elevation; which, being meaſured upon the ſcale *S*, will be 34.2 of ſuch parts as the pipe contains 100 in length. And therefore, the preſſure of the water at *A*, in the full pipe *A* 20, will be to its preſſure, if that pipe were raiſed to the perpendicular ſituation *A B*, as 34.2 to 100.

Elevate the pipe to the poſition *A* 30 on the quadrant, and if it be ſupplied with water, the water will riſe from it, into the pipe *AB*, to the height *A l*, or to the ſame level with the mouth of the pipe at 30. The ſine of this elevation, or of the angle of 30 degrees, is *c* 30; which is juſt equal to half the length of the pipe, or to 50 of ſuch parts of the ſcale, as the length of the pipe contains 100. Therefore, the preſſure of the water at *A*, in a pipe elevated 30 degrees above the horizontal level, will be equal to one half of what it would be, if the ſame pipe ſtood upright in the ſituation *A B*.

And thus, by elevating the pipe to 40, 50, 60, 70, and 80 degrees on the quadrant, the sines of these elevations will be *d* 40, *e* 50, *f* 60, *g* 70, and *h* 80; which will be equal to the heights *Am*, *An*, *Ao*, *Ap*, and *Aq*: and these

Sine of	Parts	Sine of	Parts	Sine of	Parts
D. 1	17	D. 31	515	D. 61	875
2	35	32	530	62	883
3	52	33	545	63	891
4	70	34	559	64	899
5	87	35	573	65	906
6	104	36	588	66	913
7	122	37	602	67	920
8	139	38	616	68	927
9	156	39	629	69	934
10	174	40	643	70	940
11	191	41	656	71	945
12	208	42	669	72	951
13	225	43	682	73	956
14	242	44	695	74	961
15	259	45	707	75	966
16	276	46	719	76	970
17	292	47	731	77	974
18	309	48	743	78	978
19	325	49	755	79	982
20	342	50	765	80	985
21	358	51	777	81	988
22	375	52	7[illegible]8	82	990
23	391	53	799	83	992
24	407	54	809	84	994
25	423	55	819	85	996
26	438	56	829	86	997
27	454	57	839	87	998
28	469	58	848	88	999
29	485	59	857	89	1000
30	500	60	866	90	1000

heights

heights measured upon the scale *S* will be 64.3, 76.6, 86.6, 94.0, and 98.5; which express the pressures at *A* in all these elevations, considering the pressure in the upright pipe *AB* as 100.

Because it may be of use to have the lengths of all the sines of a quadrant from 0 degrees to 90, we have given the foregoing table, shewing the length of the sine of every degree in such parts as the whole pipe (equal to the radius of the quadrant) contains 1000. Then the sines will be integral or whole parts in length. But if you suppose the length of the pipe to be divided only into 100 equal parts, the last figure of each part or sine must be cut off as a decimal; and then those which remain at the left hand of this separation will be integral or whole parts.

Thus, if the radius of the quadrant (supposed to be equal to the length of the pipe *AC*) be divided into 1000 equal parts, and the elevation be 45 degrees, the sine of that elevation will be equal to 707 of these parts: but if the radius be divided only into 100 equal parts, the same sine will be only 70.7 or $70\frac{7}{10}$ of these parts. For, as 1000 is to 707, so is 100 to 70.7.

As it is of great importance to all engine-makers, to know what quantity and weight of water will be contained in an upright round pipe of a given diameter and height; so as by knowing what weight is to be raised, they may proportion their engines to the force which they can afford to work them; we shall subjoin tables shewing the number of cubic inches of water contained in an upright pipe of a round bore, of any diameter from one inch to six and

 a half;

a half; and of any height from one foot to two hundred: together with the weight of the said number of cubic inches, both in troy and avoirdupoise ounces. The number of cubic inches divided by 231, will reduce the water to gallons in wine measure; and divided by 282, will reduce it to the measure of ale gallons. Also, the troy ounces divided by 12, will reduce the weight to troy pounds; and the avoirdupoise ounces divided by 16, will reduce the weight to avoirdupoise pounds.

And here I must repeat it again, that the weight or pressure of the water acting against the power that works the engine, must always be estimated according to the perpendicular height to which it is to be raised, without any regard to the length of the conduct-pipe, when it has an oblique position; and as if the diameter of that pipe were just equal to the diameter of that part of the pump in which the piston works. Thus, by the following tables, the pressure of the water, against an engine whose pump is of a $4\frac{1}{2}$ inch bore, and the perpendicular height of the water in the conduct-pipe is 80 feet, will be equal to 8057.5 troy ounces, and to 8848.2 avoirdupoise ounces; which makes 671.4 troy pounds, and 553 avoirdupoise.

1 Inch diameter.			
Feet high.	Solidity in cubic inches.	Weight in troy ounces.	In avoirdupoise ounces.
1	9.42	4.97	5.46
2	18.85	9.95	10.92
3	28.27	14.92	16.38
4	37.70	19.89	21.85
5	47.12	24.87	27.31
6	56.55	29.84	32.77
7	65.97	34.82	38.23
8	75.40	39.79	43.69
9	84.82	44.76	49.16
10	94.25	49.74	54.62
20	188.49	99.48	109.24
30	282.74	149.21	163.86
40	376.99	198.95	218.47
50	471.24	248.69	273.09
60	565.49	298.43	327.71
70	659.73	348.17	382.33
80	753.98	397.90	436.95
90	843.23	447.64	491.57
100	942.48	497.38	546.19
200	1884.96	994.76	1092.38

EXAMPLE. *Required the number of cubic inches, and the weight of the water, in an upright pipe 278 feet high, and $1\frac{1}{2}$ inch diameter?*

Here the nearest single decimal figure is only taken into the account; and the whole being reduced by division, amounts to $25\frac{3}{4}$ wine gallons in measure; to $259\frac{1}{4}$ pounds troy, and to $213\frac{1}{2}$ pounds avoirdupoise.

Feet	Cubic inches	Troy oz.	Avoird. oz.
200	4241.1	2238.2	2457.8
70	1484.4	783.3	860 2
8	169 6	89.5	98.3
Ans. 278	5895.1	3111.0	3416.3

 These

$1\frac{1}{2}$ Inch diameter.			
Feet high.	Solidity in cubic inches.	Weight in troy ounces.	In avoirdupoise ounces.
1	21.21	11.19	12.29
2	42.41	22.38	24.58
3	63.62	33.57	36.87
4	84.82	44.76	49.16
5	106.03	55.95	61.45
6	127.23	67.15	73.73
7	147.44	78.34	86.02
8	169.65	89.53	98.31
9	190.85	100.72	110.60
10	212.06	111.91	122.89
20	424.12	223.82	245.78
30	636.17	335.73	368.68
40	848.23	447.64	491.57
50	1060.29	559.55	614.46
60	1272.35	671.46	737.35
70	1484.40	783.37	860.24
80	1696.46	895.28	983.14
90	1908.52	1007.19	1106.03
100	2120.58	1119.09	1228.92
200	4241.15	2238.18	2457.84

These tables were at first calculated to six decimal places for the sake of exactness; but in transcribing them there are no more than two decimal figures taken into the account, and sometimes but one; because there is no necessity for

2 Inches diameter.			
Feet high.	Solidity in cubic inches.	Weight in troy ounces.	In avoirdupoise ounces.
1	37.70	19.89	21.85
2	75.40	39.79	43.69
3	113.10	59.68	65.54
4	150.80	79.58	87.39
5	188.50	99.47	109.24
6	226.19	119.37	131.08
7	263.89	139.26	152.93
8	301.59	159.16	174.78
9	339.29	179.06	196.63
10	376.99	198.95	218.47
20	753.98	397.90	436.95
30	1130.97	596.85	665.42
40	1507.97	795.80	873.90
50	1884.96	994.75	1092.37
60	2261.95	1193.70	1310.85
70	2638.94	1392.65	1529.32
80	3015.93	1591.60	1747.80
90	3392.92	1790.56	1966.27
100	3769.91	1989.51	2184.75
200	7539.82	3979.00	4369.50

for computing to hundredth parts of an inch or of an ounce in practice. And as they never appeared in print before, it may not be amiss to give the reader an account of the principles upon which they were constructed.

2½ Inches diameter.			
Feet high.	Solidity in cubic inches.	Weight in troy ounces.	In avoirdupoise ounces.
1	58.90	31.08	34.14
2	117.81	62.17	68.27
3	176.71	93.26	102.41
4	235.62	124.34	136.55
5	294.52	155.43	170.68
6	353.43	186.52	204.82
7	412.33	217.60	238.96
8	471.24	248.69	273.09
9	530.14	279.77	307.23
10	589.05	310.86	341.37
20	1178.10	621.72	682.73
30	1767.15	932.58	1024.10
40	2356.20	1243.44	1365.47
50	2545.25	1554.30	1706.83
60	3534.29	1865.16	2048.20
70	4123.34	2176.02	2389.57
80	4712.39	2486.88	2730.94
90	5301.44	2797.74	3072.30
100	5890.49	3108.60	2413.67
200	11780.98	6217.20	4827.34

The ſolidity of cylinders are found by multiplying the areas of their baſes by their altitudes. And ARCHIMEDES gives the following proportion for finding the area of a circle, and the ſolidity of a cylinder raiſed upon that circle.

As

3 Inches diameter.			
Feet high.	Solidity in cubic inches.	Weight in troy ounces.	In avoirdupoise ounces.
1	84.8	44.76	49.16
2	169.6	89.53	98.31
3	254.5	134.29	147.47
4	239.3	179.06	196.63
5	424.1	223.82	245.78
6	508.9	268.58	294.94
7	593.7	313.35	344.10
8	698.6	358.11	393.25
9	763.4	402.87	442.41
10	848.2	447.64	491.57
20	1696.5	895.28	983.14
30	2244.7	1342.92	1474.70
40	3392.9	1790.56	1966.27
50	4241.1	2238.19	2457.84
60	5089.4	2685.83	2949.41
70	5937.6	3133.47	3440.98
80	6785.8	3581.11	3932.55
90	7634.1	4028.75	4424.12
100	8482.3	4476.39	4915.68
200	16964.6	8952.78	9831.36

As 1 is to 0.785399, so is the square of the diameter to the area of the circle. And as 1 is to 0.785399, so is the square of the diameter multiplied by the height to the solidity of the cylinder. By this analogy the solid inches and parts

3½ Inches diameter.			
Feet high.	Solidity in cubic inches.	Weight in troy ounces.	In avoirdupoise ounces.
1	115.4	60.9	66.9
2	230.9	121.8	133.8
3	346.4	182.8	200.7
4	461.8	243.7	267.6
5	577.3	304.6	334.5
6	692.7	365.6	401.4
7	808.2	426.5	468.4
8	923.6	487.4	535.3
9	1039.1	548.3	602.2
10	1154.5	609.3	669.1
20	2309.1	1218.6	1338.2
30	3463.6	1827.9	2007.2
40	4618.1	2437.1	2676.3
50	5772.7	3046.4	3345.4
60	6927.2	3655.7	4014.5
70	8081.7	4265.0	4683.6
80	9236.3	4874.3	5352.6
90	10390.8	5483.6	6021.7
100	11545.4	6092.9	6690.8
200	23090.7	12185.7	13381.5

parts of an inch in the tables are calculated to a
cylinder 200 feet high, of any diameter from
inch to 6½, and may be continued at pleasure.

And as to the weight of a cubic foot of running
water, it has been often found upon trial, by
Dr

4 Inches diameter.			
Feet high.	Solidity in cubic inches.	Weight in troy ounces.	In avoirdupoise ounces.
1	150.8	79.6	87.4
2	301.6	159.2	174.8
3	452.4	238.7	262.2
4	603.2	318.3	349.6
5	754.0	397.9	436.9
6	904.8	477.5	524.3
7	1055.6	557.1	611.7
8	1206.4	636.6	699.1
9	1357.2	716.2	786.5
10	1508.0	795.8	873.9
20	3115.9	1591.6	1747.8
30	4523.9	2387.4	2621.7
40	6631.9	3183.2	3495.6
50	7539.8	3997.0	4369.5
60	9047.8	4774.8	5243.4
70	10555.8	5570.6	6117.3
80	12063.7	6366.4	6901.2
90	13571.7	7162.2	7865.1
100	15079.7	7958.0	8739.0
200	30159.3	15916.0	17478.0

r. *Wyberd* and others, to be 76 pounds troy, which is equal to 62.5 pounds avoirdupoise. Therefore, since there are 1728 cubic inches in a cubic foot, a troy ounce of water contains 1.8949 cubic inch; and an avoirdupoise ounce

The weight of running water.

4½ Inches diameter.			
Feet high.	Solidity in cubic inches.	Weight in troy ounces.	In avoirdupoise ounces.
1	190.8	100.7	110.6
2	381.7	201.4	221.2
3	572.6	302.2	331.8
4	763.4	402.9	442.4
5	954.3	503.6	553.0
6	1145.1	604.3	663.6
7	1337.9	705.0	774.2
8	1526.8	805.7	884.8
9	1717.7	906.5	995.4
10	1908.5	1007.2	1106.0
20	3817.0	2014.4	2212.1
30	5725.6	3021.6	3818.1
40	7634.1	4028.7	4424.1
50	9542.6	5035.9	5530.1
60	11451.1	6043.1	6636.2
70	13359.6	7050.3	7742.2
80	15268.2	8057.5	8848.2
90	17176.7	9064.7	9954.3
100	19085.2	10071.9	11060.3
200	38170.4	20143.8	22120.6

ounce of water 1.72556 cubic inch. Con-
quently, if the number of cubic inches co-
tained in any given cylinder, be divided
1.8949, it will give the weight in troy ounce
and divided by 1.72556, will give the weig

5 Inches diameter.			
Feet high.	Solidity in cubic inches.	Weight in troy ounces.	In avoirdupoise ounces.
1	235.6	124.3	136.5
2	471.2	248.7	273.1
3	706.8	373.0	409.6
4	942.5	497.4	546.2
5	1178.1	621.7	682.7
6	1413.7	746.1	819.3
7	1649.3	870.4	955.8
8	1884.9	994.8	1092.4
9	2120.6	1119.1	1228.9
10	2356.2	1243.4	1365.5
20	4712.4	2486.9	2730.9
30	7068.6	3730.3	4096.4
40	9424.8	4973.8	5461.9
50	11780.0	6217.2	6827.3
60	14137.2	7460.6	8192.8
70	16493.4	8704.1	9558.3
80	18849.6	9947.5	10923.7
90	21205.8	11191.0	12289.2
100	23562.0	12434.4	13654.7
200	47124.0	24868.8	27309.3

n avoirdupoise ounces. By this method, the weights shewn in the tables were calculated; and are near enough for any common practice.

The *fire-engine* comes next in order to be explained: but as it would be difficult, even by the The *fire-engine.*

5½ Inches diameter.			
Feet high.	Solidity in cubic inches.	Weight in troy ounces.	In avoirdupoiſe ounces.
1	285.1	150.5	164.3
2	570.2	300.9	328.5
3	855.3	451.4	492.8
4	1140.4	601.8	657.1
5	1425.5	752.3	821.3
6	1710.6	902.7	985.6
7	1995.7	1053.2	1149.9
8	2280.8	1203.6	1314.2
9	2565.9	1354.1	1478.4
10	2851.0	1504.6	1642.7
20	5702.0	3009.1	3285.4
30	8553.0	4513.7	4928.1
40	11404.0	6018.2	6570.8
50	14255.0	7522.8	8213.5
60	17106.0	9027.4	9856.2
70	19957.0	10531.9	11498.9
80	22808.0	12036.5	13141.6
90	25659.0	13541.1	14784.3
100	28510.0	15045.6	16426.9
200	57020.0	30091.2	32853.9

the beſt place to give a particular deſcriptio of its ſeveral parts, ſo as to make the whol intelligible, I ſhall only explain the princip upon which it is conſtructed.

1. Wha

6 Inches diameter.			
Feet high.	Solidity in cubic inches.	Weight in troy ounces.	In avoirdupoise ounces.
1	339.3	179.0	196.6
2	678.6	358.1	393.3
3	1017.9	537.2	589.9
4	1357.2	716.2	786.5
5	1696.5	895.3	983.1
6	2035.7	1074.3	1179.8
7	2375.0	1253.4	1376.4
8	2714.3	1432.4	1573.0
9	3053.6	1611.5	1769.6
10	3392.9	1790.6	1966.3
20	6785.8	3581.1	3932.5
30	10178.8	5371.7	5898.8
40	13571.7	7162.2	7865.1
50	16964.6	8952.8	9831.4
60	20357.5	10743.3	11797.6
70	23750.5	12533.9	13763.9
80	27143.4	14324.4	15730.2
90	30536.3	16115.0	17696.5
100	33929.2	17905.6	19662.7
200	67858.4	35811.2	39325.4

n. Whatever weight of water is to be raised, pump-rod must be loaded with weights sufent for that purpose, if it be done by a ing-pump, as is generally the case: and the

4 power

6½ Inches diameter.			
Feet high.	Solidity in cubic inches.	Weight in troy ounces.	In avoirdupoise ounces.
1	398.2	210.1	230.7
2	797.4	420.3	461.4
3	1195.6	630.4	692.1
4	1593.8	840.6	922.8
5	1991.9	1050.8	1153.6
6	2390.1	1260.9	1384.3
7	2788.3	1471.1	1615.0
8	3186.5	1681.2	1845.7
9	3584.7	1891.3	2076.4
10	3982.9	2101.5	2307.1
20	7965.8	4202.9	4614.3
30	11948.8	6304.4	6921.4
40	15931.7	8405.9	9228.6
50	19914.6	10507.4	11535.7
60	23897.6	12608.9	13842.9
70	27880.5	14710.4	16150.0
80	31863.4	16811.8	18457.2
90	35846.3	18913.3	20764.3
100	39829.3	21014.8	23071.5
200	79658.6	42029.6	46143.0

power of the engine must be sufficient for th weight of the rod, in order to bring it up.

2. It is known, that the atmosphere press upon the surface of the earth with a force equ to 15 pounds upon every square inch.

3. Wh

3. When water is heated to a certain degree, the particles thereof repel one another, and constitute an elastic fluid, which is generally called *steam* or *vapour*.

4. Hot steam is very elastic; and when it is cooled by any means, particularly by its being mixed with cold water, its elasticity is destroyed immediately, and it is reduced to water again.

5. If a vessel be filled with hot steam, and then closed so, as to keep out the external air, and all other fluids; when that steam is by any means condensed, cooled, or reduced to water, *that* water will fall to the bottom of the vessel; and the cavity of the vessel will be almost a perfect vacuum.

6. Whenever a vacuum is made in any vessel, the air by its weight will endeavour to rush into the vessel, or to drive in any other body that will give way to its pressure; as may be easily seen by a common syringe. For, if you stop the bottom of a syringe, and then draw up the piston, if it be so tight as to drive out all the air before it, and leave a vacuum within the syringe, the piston being let go will be driven down with a great force.

7. The force with which the piston is drove down, when there is a vacuum under it, will be as the square of the diameter of the bore in the syringe. That is to say, it will be driven down with four times as much force in a syringe of a two-inch bore, as in a syringe of one inch: for the areas of circles are always as the squares of their diameters.

8. The pressure of the atmosphere being equal to 15 pounds upon every square inch, it will be equal to about 12 pounds upon every circular inch. So that if the bore of the syringe

be round, and one inch in diameter, the piston will be preſt down into it by a force nearly equal to 12 pounds: but if the bore be two inches diameter, the piston will be preſt down with four times that force.

And hence it is eaſy to find with what force the atmoſphere preſſes upon any given number either of ſquare or circular inches.

Theſe being the principles upon which this engine is conſtructed, we ſhall next deſcribe the chief working parts of it: which are, 1. A boiler. 2. A cylinder and piſton. 3. A beam or lever.

The *boiler* is a large veſſel made of iron or copper; and commonly ſo big as to contain about 2000 gallons.

The *cylinder* is about 40 inches diameter, bored ſo ſmooth, and its leathered piſton fitting ſo cloſe, that little or no water can get between the piſton and ſides of the cylinder.

Things being thus prepared, the cylinder is placed upright, and the ſhank of the piſton is fixed to one end of the *beam*, which turns on a center like a common balance.

The boiler is placed under the cylinder, with a communication between them, which can be opened and ſhut occaſionally.

The boiler is filled about half full of water, and a ſtrong fire is made under it: then, if the communication between the boiler and the cylinder be opened, the cylinder will be filled with hot ſteam; which would drive the piſton quite out at the top of it. But there is a contrivance by which the piſton, when it is near the top of the cylinder, ſhuts the communication at the top of the boiler within.

Th

This is no ſooner ſhut, than another is opened, by which a little cold water is thrown upwards in a jet into the cylinder, which mixing with the hot ſteam, condenſes it immediately; by which means a vacuum is made in the cylinder, and the piſton is preſſed down by the weight of the atmoſphere; and ſo lifts up the loaded pump-rod at the other end of the beam.

If the cylinder be 42 inches in diameter, the piſton will be preſſed down with a force greater than 20000 pounds, and will conſequently lift up that weight at the oppoſite end of the beam: and as the pump-rod with its plunger is fixed to that end, if the bore where the plunger works were 10 inches diameter, the water would be forced up through a pipe of 180 yards perpendicular height.

But, as the parts of this engine have a good deal of friction, and muſt work with a conſiderable velocity, and there is no ſuch thing as making a perfect vacuum in the cylinder, it is found that no more than 8 pounds of preſſure muſt be allowed for, on every circular inch of the piſton in the cylinder, that it may make about 16 ſtrokes in a minute, about 6 feet each.

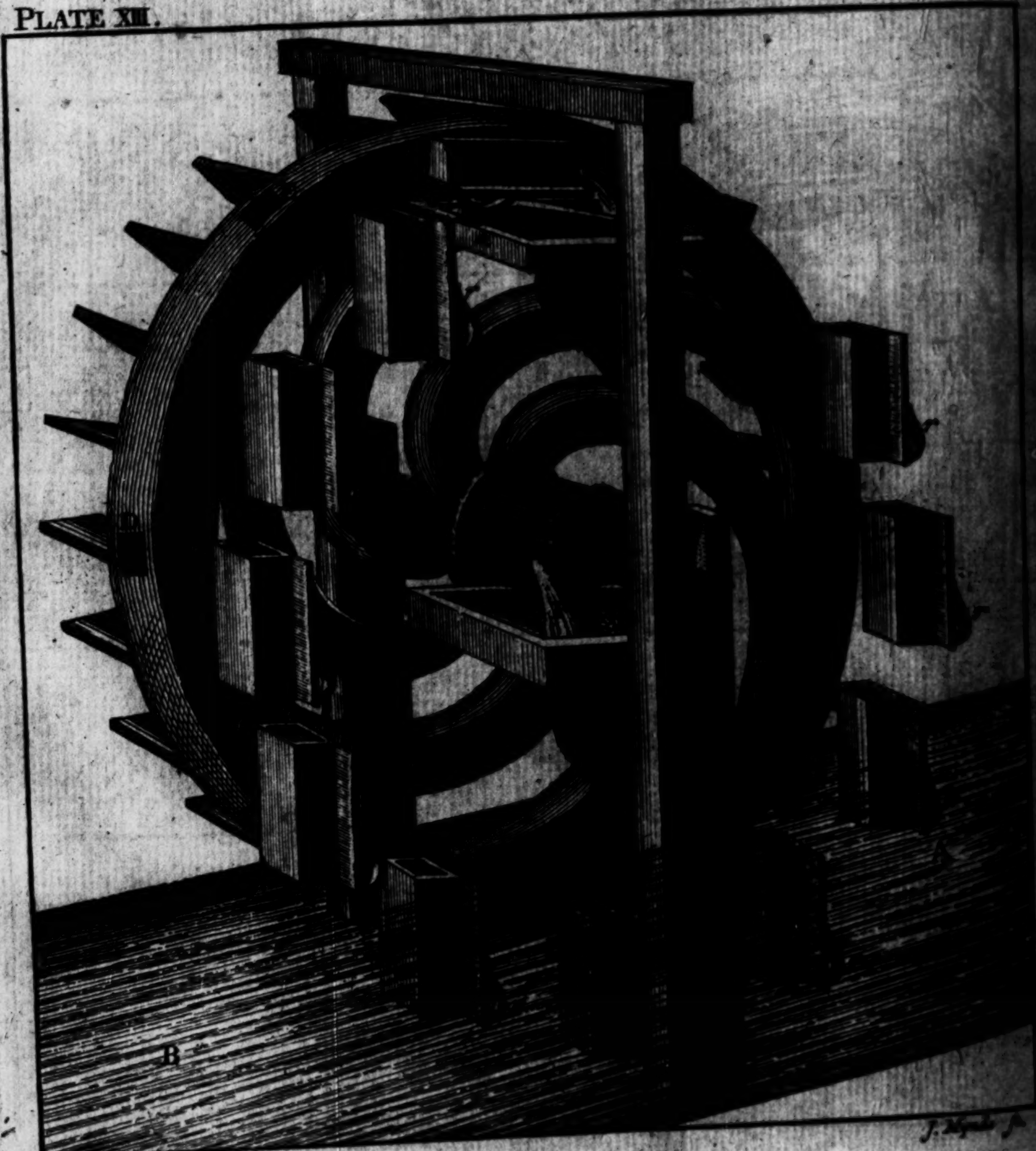
Where the boiler is very large, the piſton will make between 20 and 25 ſtrokes in a minute, and each ſtroke 7 or 8 feet; which, in a pump of 9 inches bore, will raiſe upwards of 300 hogſheads of water in an hour.

It is found by experience that a cylinder, 40 inches diameter, will work a pump 10 inches diameter, and 100 yards long: and hence we can find the diameter and length of a pump, that can be worked by any other cylinder.

For the conveniency of thoſe who would make uſe of this engine for raiſing water, we ſhall ſubjoin part of a table calculated by Mr. *Beighton*, ſhewing how any given quantity of water may be raiſed in an hour, from 48 to 440 hogſheads; at any given depth, from 15 to 100 yards; the machine working at the rate of 16 ſtrokes *per* minute, and each ſtroke being 6 feet long.

One example of the uſe of this table, will make the whole plain. Suppoſe it were required to draw 150 hogſheads *per* hour, at 90 yards depth; in the ſecond column from the right hand, I find the neareſt number, viz. 149 hogſheads 40 gallons, againſt which, on the right hand, I find the diameter of the bore of the pump muſt be 7 inches; and in the ſame collateral line, under the given depth 90, I find 27 inches, the diameter of the cylinder fit for that purpoſe.— And ſo for any other.

PLATE XIII.



J. Ferguson delin.

J. Mynde sc.

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A Table shewing the power of the engine for raising water by fire.

Diameter of the cylinder in inches.	The depth to be drawn in yards.													In one hour.		Diam. of pump.
	15	20	25	30	35	40	45	50	60	70	80	90	100	Hogsh.	Gal.	Inches.
	18½	21¾	24	26½	28½	30½	32½	34¼	37½	40	—	—	—	440		12
	17	19¾	22	34¾	26¼	28	29¾	31¼	34¼	37	39½	—	—	369	33	11
	15½	18	20	22	23¾	25½	27	28¾	31¼	33¾	36	38¼	40	304	48	10
	14	16¼	18	20	21½	23	24¼	25	28	30½	33	35	36½	247	7	9
	13½	15½	17¼	19	20¼	21¾	23	24	26¼	28½	31	32½	35¼	221	15	8½
	12½	14½	16½	18½	19	20½	21½	23	25	27	29	30½	32½	195	22	8
	12	14	15½	17½	18¾	19¾	21	22	24¼	26	28	29½	31½	182	13	7¾
	11	13¾	15	16½	18	19	20	21¼	23¼	25	27	28½	30¼	172	30	7½
	10¾	13	14	15½	16¾	18¾	19	20½	22	24	25½	27	28½	149	40	7
	10	12	13	14	15½	16¼	18	19	20	22	23	24½	26¼	128	54	6½
	9½	11	12	13	14	15½	16	17	19	20½	22	23	24½	110	1	6
		10	11	12	13	14	15	15¾	17	19	20	21	22¼	94	30	5½
			10	11	11¾	13	13¾	14	15½	16¾	18½	19½	20¼	66	61	5
				10	10	11¼	12	13½	14	15	16	17	18¼	60	60	4½
					9	10	11	11½	12	13½	14	15	16	48	51	4

This table is calculated to the measure of ale gallons, at 282 cubic inches *per* gallon.

Plate XIII. The Persian wheel.

Water may be raiſed by means of a ſtream *A B* turning a wheel *C D E*, according to the order of the letters, with buckets *a*, *a*, *a*, *a*, &c. hung upon the wheel by ſtrong pins *b*, *b*, *b*, *b*, &c. fixed in the ſide of the rim: but the wheel muſt be made as high as the water is intended to be raiſed above the level of that part of the ſtream in which the wheel is placed. As the wheel turns, the buckets on the right hand go down into the water, and are thereby filled, and go up full on the left hand, until they come to the top at *K*; where they ſtrike againſt the end *n* of the fixed trough *M*, and are thereby overſet, and empty the water into the trough; from which it may be conveyed in pipes to the place which it is deſigned for: and as each bucket gets over the trough, it falls into a perpendicular poſition again, and goes down empty, until it comes to the water at *A*, where it is filled as before. On each bucket is a ſpring *r*, which going over the top or crown of the bar *m* (fixed to the trough *M*) raiſes the bottom of the bucket above the level of its mouth, and ſo cauſes it to empty all its water into the trough.

Sometimes this wheel is made to raiſe water no higher than its axis; and then, inſtead of buckets hung upon it, its ſpokes *C*, *d*, *e*, *f*, *g*, *h* are made of a bent form, and hollow within; theſe hollows opening into the holes *C*, *D*, *E*, *F*, in the outſide of the wheel, and alſo into thoſe at *O* in the box *N* upon the axis. So that, as the holes *C*, *D*, &c. dip into the water, it runs into them; and as the wheel turns, the water riſes in the hollow ſpokes, *c*, *d*, &c. and runs out in a ſtream *P* from the holes at *O*, and falls into the trough *Q*, from whence it is conveyed by pipes. And this is a very eaſy way of raiſing

water, because the engine requires neither men nor horses to turn it.

The art of weighing different bodies in water, and thereby finding their specific gravities, or weights, bulk for bulk, was invented by ARCHIMEDES; of which, we have the following account.

Of the specific gravities of bodies.

Hiero, king of *Syracuse*, having employed a goldsmith to make a crown, and given him a mass of pure gold for that purpose, suspected that the workman had kept back part of the gold for his own use, and made up the weight by allaying the crown with copper. But the king not knowing how to find out the truth of that matter, referred it to *Archimedes*; who having studied a long time in vain, found it out at last by chance. For, going into a bathing tub of water, and observing that he thereby raised the water higher in the tub than it was before, he concluded instantly that he had raised it just as high as any thing else could have done, that was exactly of his bulk: and considering that any other body of equal weight, and of less bulk than himself, could not have raised the water so high as he did; he immediately told the king, that he had found a method by which he could discover whether there were any cheat in the crown. For, since gold is the heaviest of all known metals, it must be of less bulk, according to its weight, than any other metal. And therefore, he desired that a mass of pure gold, equally heavy with the crown when weighed in air, should be weighed against it in water; and if the crown was not allayed, it would counterpoise the mass of gold when they were both immersed in water, as well as it did when they were weighed in air. But upon

making the tryal, he found that the mass of gold weighed much heavier in water than the crown did. And not only so, but that, when the mass and crown were immersed separately in one vessel of water, the crown raised the water much higher than the mass did; which shewed it to be allayed with some lighter metal that increased its bulk. And so, by making trials with different metals, all equally heavy with the crown when weighed in air, he found out the quantity of allay in the crown.

The specific gravities of bodies are as their weights, bulk for bulk; thus a body is said to have two or three times the specific gravity of another, when it contains two or three times as much matter in the same space.

A body immersed in a fluid will sink to the bottom, if it be heavier than its bulk of the fluid. If it be suspended therein, it will lose as much of what it weighed in air, as its bulk of the fluid weighs. Hence, all bodies of equal bulk, which would sink in fluids, lose equal weights when suspended therein. And unequal bodies lose in proportion to their bulks.

The *hydrostatic balance.*

The *hydrostatic balance* differs very little from a common balance that is nicely made: only it has a hook at the bottom of each scale, on which small weights may be hung by horse-hairs, or by silk threads. So that a body, suspen'ed by the hair or thread, may be immersed in water without wetting the scale from which it hangs.

How to find the specific gravity of any body.

If the body thus suspended under the scale, at one end of the balance, be first counterpoised in air by weights in the opposite scale, and then immersed in water, the equilibrium will be immediately destroyed. Then, if as much weight be

be put into the scale from which the body hangs, as will restore the equilibrium (without altering the weights in the opposite scale) that weight which restores the equilibrium, will be equal to the weight of a quantity of water as big as the immersed body. And if the weight of the body in air be divided by what it loses in water, the quotient will shew how much that body is heavier than its bulk of water. Thus, if a guinea suspended in air, be counterbalanced by 129 grains in the opposite scale of the balance; and then, upon its being immersed in water, it becomes so much lighter, as to require $7\frac{1}{4}$ grains put into the scale over it, to restore the equilibrium, it shews that a quantity of water, of equal bulk with the guinea, weighs $7\frac{1}{4}$ grains, or 7.25; by which divide 129 (the weight of the guinea in air) and the quotient will be 17.793; which shews that the guinea is 17.793 times as heavy as its bulk of water. And thus, any piece of gold may be tried, by weighing it first in air, and then in water; and if upon dividing the weight in air by the loss in water, the quotient comes out to be 17.793, the gold is good; if the quotient be 18, or between 18 and 19, the gold is very fine; but if it be less than 17, the gold is too much allayed, by being mixed with some other metal.

If silver be tried in this manner, and found to be 11 times as heavy as water, it is very fine; if it be $10\frac{1}{2}$ times as heavy, it is standard; but if it be of any less weight compared with water, it is mixed with some lighter metal, such as tin.

By this method, the specific gravities of all bodies that will sink in water, may be found. But as to those which are lighter than water, as most

most sorts of wood are, the following method may be taken, to shew how much lighter they are than their respective bulks of water.

Let an upright stud be fixed into a thick flat piece of brass, and in this stud let a small lever, whose arms are equally long, turn upon a fine pin as an axis. Let the thread which hangs from the scale of the balance be tied to one end of the lever, and a thread from the body to be weighed, tied to the other end. This done, put the brass and lever into a vessel; then pour water into the vessel, and the body will rise and float upon it, and draw down the end of the balance from which it hangs: then, put as much weight in the opposite scale as will raise that end of the balance, so as to pull the body down into the water by means of the lever; and this weight in the scale will shew how much the body is lighter than its bulk of water.

There are some things which cannot be weighed in this manner, such as quicksilver, fragments of diamonds, &c. because they cannot be suspended in threads; and must therefore be put into a glass bucket, hanging by a thread from the hook of one scale, and counterpoised by weights put into the oppsite scale. Thus, suppose you want to know the specific gravity of quicksilver, with respect to that of water; let the empty bucket be first counterpoised in air, and then the quicksilver put into it and weighed. Write down the weight of the bucket, and also of the quicksilver; which done, empty the bucket, and let it be immersed in water as it hangs by the thread, and counterpoised therein by weights in the opposite scale: then, pour the quicksilver into the bucket in the water, which will cause it to preponderate; and put as much

much weight into the opposite scale as will restore the balance to an equipoise; and this weight will be the weight of a quantity of water equal in bulk to the quicksilver. Lastly, divide the weight of the quicksilver in air, by the weight of its bulk of water, and the quotient will shew how much the quicksilver is heavier than its bulk of water.

If a piece of brass, glass, lead, or silver, be immersed and suspended in different sorts of fluids, its different losses of weight therein will shew how much it is heavier than its bulk of the fluid; the fluid being lightest, in which the immersed body loses least of its aerial weight. A solid bubble of glass is generally used for finding the specific gravities of fluids.

Hence we have an easy method of finding the specific gravities both of solids and fluids, with regard to their respective bulks of common pump water, which is generally made a standard for comparing all the others by.

In constructing tables of specific gravities with accuracy, the gravity of water must be represented by unity or 1.000, where three cyphers are added, to give room for expressing the ratios of other gravities in decimal parts, as in the following table.

A Table

A Table of the specific gravities of several solid and fluid bodies.

A cubic inch of	Troy weight. oz.	pw.	gr.	Avoirdup. oz.	drams.	Comparative weight.
Very fine gold -	10	7	3.83	1	5.80	19.637
Standard gold -	9	19	6.44	10	14.90	18.888
Guinea gold -	9	7	17.18	10	4.76	17.793
Moidore gold -	9	0	19.84	9	14.71	17.140
Quickfilver - -	7	7	11.61	8	1.45	14.019
Lead - -	5	19	17.55	6	9.08	11.325
Fine filver - -	5	16	23.23	6	6.66	11.087
Standard filver -	5	11	3.36	6	1.54	10.535
Copper - -	4	13	7.04	5	1.89	8.843
Plate brafs -	4	4	9.60	4	10.09	8.000
Steel - - -	4	2	20.12	4	8.70	7.852
Iron - - -	4	0	15.20	4	6.77	7.645
Block tin - -	3	17	5.68	4	3.79	7.321
Speltar - -	3	14	12.86	4	1.42	7.065
Lead ore - -	3	11	17.76	3	14.96	6.800
Glafs of antimony	2	15	16.89	3	0.89	5.280
German antimony	2	2	4.80	2	5.04	4.000
Copper ore -	2	1	11.83	2	4.43	3.775
Diamond - -	1	15	20.88	1	15.48	3.400
Clear glafs - -	1	13	5.58	1	13.16	3.150
Lapis lazuli -	1	12	5.27	1	12.27	3.054
Welch afbeftos -	1	10	17.57	1	10.97	2.913
White marble -	1	8	13.41	1	9.06	2.707
Black ditto -	1	8	12.65	1	9.02	2.704
Rock cryftal -	1	8	1.00	1	8.61	2.658
Green glafs - -	1	7	15.38	1	8.26	2.620
Cornelian ftone -	1	7	1.21	1	7.73	2.568
Flint - -	1	6	19.63	1	7.53	2.542
Hard paving ftone	1	5	22.87	1	6.77	2.460
Live fulphur -	1	1	2.40	1	2.52	2.000
Nitre - - -	1	0	1.08	1	1.59	1.900
Alabafter - -	0	19	18.74	1	1.35	1.875
Dry ivory - -	0	19	6.09	1	0.89	1.825
Brimftone - -	0	18	23.76	1	0.66	1.800
Alum - -	0	17	21.92	0	15.72	1.714

The Table concluded.

A cubic inch of	Troy weight. oz.	pw.	gr.	Avoirdup. oz.	drams.	Comparative weight
Ebony - -	0	11	18.82	0	10.34	1.117
Human blood -	0	11	2.89	0	9.76	1.054
Amber - -	0	10	20.79	0	9.54	1.030
Cow's milk -	0	10	20.79	0	9.54	1.030
Sea water - -	0	10	20.79	0	9.54	1.030
Pump water -	0	10	13.30	0	9.26	1.000
Spring water -	0	10	12.94	0	9.25	0.999
Distilled water -	0	10	11.42	0	9.20	0.993
Red wine - -	0	10	11.42	0	9.20	0.993
Oil of amber -	0	10	7.63	0	9.06	0.978
Proof spirits -	0	9	19.73	0	8.62	0.931
Dry oak - -	0	9	18.00	0	8.56	0.925
Olive oil - -	0	9	15.17	0	8.45	0.913
Pure spirits - -	0	9	3.27	0	8.02	0.866
Spirit of turpentine	0	9	2.76	0	7.99	0.864
Oil of turpentine	0	8	8.53	0	7.33	0.772
Dry Crabtree -	0	8	1.69	0	7.08	0.765
Sassafras wood -	0	5	2.04	0	4.46	0.482
Cork - -	0	2	12.77	0	2.21	0.240

Take away the decimal point from the numbers in the right hand column, or (which is the same) multiply them by 1000, and they will shew how many ounces avoirdupoise are contained in a cubic foot of each body.

How to find out the quantity of adulteration in metals.

The use of the table of specific gravities will best appear by an example. Suppose a body to be compounded of gold and silver, and it is required to find the quantity of each metal in the compound.

First find the specific gravity of the compound, by weighing it in air and in water, and dividing its aerial weight by what it loses thereof in water, the quotient will shew its specific gravity,

gravity, or how many times it is heavier than its bulk of water. Then, ſubtract the ſpecific gravity of ſilver (found in the table) from that of the compound, and the ſpecific gravity of the compound from that of gold; the firſt remainder ſhews the bulk of gold, and the latter the bulk of ſilver, in the whole compound: and if theſe remainders be multiplied by the reſpective ſpecific gravities, the products will ſhew the proportion of weights of each metal in the body. Example.

Suppoſe the ſpecific gravity of the compounded body be 13; that of ſtandard ſilver (by the table) is 10.5, and that of gold 19.63: therefore 10.5 from 13, remains 2.5, the proportional bulk of the gold; and 13 from 19.63, remains 6.63, the proportional bulk of ſilver in the compound. Then, the firſt remainder 2.5, multiplied by 19.63, the ſpecific gravity of gold, produces 49.075 for the proportional weight of gold; and the laſt remainder 6.63 multiplied by 10.5, the ſpecific gravity of ſilver, produces 69.615 for the proportional weight of ſilver in the whole body. So that for every 49.07 ounces or pounds of gold, there are 69.6 pounds or ounces of ſilver in the body.

Hence it is eaſy to know whether any ſuſpected metal be genuine, or allayed, or counterfeit; by finding how much it is heavier than its bulk of water, and comparing the ſame with the table: if they agree, the metal is good; if they differ, it is allayed or counterfeited.

How to try ſpirituous liquors.

A cubical inch of good brandy, rum, or other proof ſpirits, weighs 235.7 grains; therefore, if a true inch cube of any metal weighs 235.7 grains leſs in ſpirits than in air, it ſhews the ſpirits are proof. If it loſes leſs of its aerial weight

weight in spirits, they are above proof; if it loses more, they are under. For, the better the spirits are, they are the lighter; and the worse, the heavier. All bodies expand with heat and contract with cold, but some more and some less than others. And therefore the specific gravities of bodies are not precisely the same in summer as in winter. It has been found, that a cubic inch of good brandy is 10 grains heavier in winter than in summer; as much spirit of nitre, 20 grains; vinegar 6 grains, and spring water 3. Hence it is most profitable to buy spirits in winter, and sell them in summer, since they are always bought and sold by measure. It has been found, that 32 gallons of spirits in winter will make 33 in summer.

The expansion of all fluids is proportionable to the degree of heat; that is, with a double or triple heat a fluid will expand two or three times as much.

Upon these principles depends the construction of the thermometer, in which the globe or bulb, and part of the tube, are filled with a fluid, which, when joined to the barometer, is spirits of wine tinged, that it may be more easily seen in the tube. But when thermometers are made by themselves, quicksilver is generally used. The *thermometer.*

In the thermometer, a scale is fitted to the tube, to shew the expansion of the quicksilver, and consequently the degree of heat. And, as *Farenheit*'s scale is most in esteem at present, I shall explain the construction and graduation of thermometers according to that scale.

First, let the globe or bulb, and part of the tube, be filled with a fluid; then immerse the bulb in water just freezing, or snow just thawing;

ing; and even with that part in the scale where the fluid then stands in the tube, place the number 32, to denote the freezing point: then put the bulb under your arm-pit, when your body is of a moderate degree of heat, so that it may acquire the same degree of heat with your skin; and when the fluid has risen as far as it can by that heat, there place the number 97: then divide the space between these numbers into 65 equal parts, and continue those divisions both above 97 and below 32, and number them accordingly.

This may be done in any part of the world; for it is found that the freezing point is always the same in all places, and the heat of the human body differs but very little; so that the thermometers made in this manner will agree with one another; and the heat of several bodies will be shewn by them, and expressed by the numbers upon the scale, thus.

Air, in severe cold weather, in our climate, from 15 to 25. Air in winter, from 26 to 42. Air in spring and autumn, from 43 to 53. Air at midsummer, from 65 to 68. Extreme heat of the summer sun, from 86 to 100. Butter just melting, 95. Alcohol boils with 174 or 175. Brandy with 190. Water 212. Oil of turpentine 550. Tin melts with 408, and lead with 540. Milk freezes about 30, vinegar 28, and blood 27.

A body specifically lighter than a fluid will swim upon its surface, in such a manner, that a quantity of the fluid equal in bulk with the immersed part of the body, will be as heavy as the whole body. Hence, the lighter a fluid is, the deeper a body will sink in it; upon which depends

depends the construction of the *hydrometer* or water-poise.

From this we can easily find the weight of a ship, or any other body that swims in water. For, if we multiply the number of cubic feet which are under the surface, by 62.5, the number of pounds in one foot of fresh water; or by 63, the number of pounds in a foot of salt water; the product will be the weight of the ship, and all that is in it. For, since it is the weight of the ship that displaces the water, it must continue to sink until it has removed as much water as is equal to it in weight: and therefore the part immersed must be equal in bulk to such a portion of the water as is equal to the weight of the whole ship.

How the weight of a ship in water may be estimated.

To prove this by experiment, let a ball of some light wood, such as fir or pear-tree, be put into water contained in a glass vessel; and let the vessel be put into a scale at one end of a balance, and counterpoised by weights in the opposite scale: then, marking the height of the water in the vessel, take out the ball; and fill up the vessel with water to the same height that it stood at when the ball was in it; and the same weight will counterpoise it as before.

From the vessel's being filled up to the same height at which the water stood when the ball was in it, it is evident that the quantity poured in is equal in magnitude to the immersed part of the ball; and from the same weight counterpoising, it is plain that the water poured in, is equal in weight to the whole ball.

In troy weight, 24 grains make a pennyweight, 20 pennyweight make an ounce, and 12 ounces a pound. In avoirdupoise weight, 16 drams make an ounce, and 16 ounces a

 pound.

pound. The troy pound contains 5760 grains, and the avoirdupoise pound 7000; and hence, the avoirdupoise dram weighs 27.34375 grains, and the avoirdupoise ounce 437.5.

Because it is often of use to know how much any given quantity of goods in troy weight do make in avoirdupoise weight, and the reverse; we shall here annex two tables for converting these weights into one another. Those from page 133 to page 144 are near enough for common hydraulic purposes; but the two following are better, where accuracy is required in comparing the weights with one another: and I find, by trial, that 175 troy ounces are precisely equal to 192 avoirdupoise ounces, and 175 troy pounds are equal to 144 avoirdupoise. And although there are several lesser integral numbers, which come very near to agree together, yet I have found none less than the above to agree exactly. Indeed 41 troy ounces are so nearly equal to 45 avoirdupoise ounces, that the latter contains only $7\frac{1}{2}$ grains more than the former: and 45 troy pounds weigh only $7\frac{3}{10}$ drams more than 37 avoirdupoise.

A table for reducing Troy weight into Avoirdupoise weight.

Troy weight.	Avoirdupoise. lb.	oz.	drams.	Troy weight.		Avoir. Drams
Pounds — 4000	3291	6	13.68	Penny wt.	19	16.67
3000	2528	9	2.26		18	15.79
2000	1645	11	6.84		17	14.92
1000	822	13	11.42		16	14.04
900	740	9	2.28		15	13.16
800	658	4	9.14		14	12.29
700	576	9	0.00		13	11.41
600	493	11	6.85		12	10.53
500	411	6	13.71		11	9.65
400	329	2	4.57		10	8.78
300	246	13	11.42		9	7.90
200	164	9	2.28		8	7.02
100	82	4	9.15		7	6.14
90	74	0	13.62		6	5.27
80	65	13	4.11		5	4.39
70	57	9	9.60		4	3.51
60	49	5	15.08		3	2.63
50	41	2	4.57		2	1.75
40	32	14	10.05		1	0.88
30	24	10	15.54	Grains —	23	.84
20	16	7	5.03		22	.80
10	8	3	10.52		21	.77
9	7	6	7.86		20	.73
8	6	9	5.21		19	.69
7	5	12	2.56		18	.66
6	4	14	15.90		17	.62
5	4	1	13.25		16	.58
4	3	4	10.60		15	.55
3	2	7	7.95		14	.51
2	1	10	5.30		13	.47
1	0	13	2.65		12	.44
Ounces — 11		12	1.09		11	.40
10		10	15.54		10	.36
9		9	13.99		9	.33
8		8	12.43		8	.29
7		7	10.88		7	.26
6		6	9.32		6	.22
5		5	7.77		5	.18
4		4	6.22		4	.15
3		3	4.66		3	.11
2		2	3.11		2	.07
1		1	1.55		1	.04

A Table for reducing Avoirdupoise weight into Troy weight.

Avoirdupoise weight.		Troy weight. lb.	oz.	pw.	gr.	Avoird. weight.		Troy weight. lb.	oz.	pw.	gr.
Pounds	6000	7291	8	0	0	Ounces	15	1	1	13	10.50
	5000	6076	4	13	8		14	1	0	15	5
	4000	4861	1	6	16		13		11	16	23.50
	3000	3645	10	0	0		12		10	18	18
	2000	2430	6	13	8		11		10	0	12.50
	1000	1215	3	6	16		10		9	2	7
	900	1093	9	0	0		9		8	4	1.50
	800	972	2	13	8		8		7	5	20
	700	850	8	6	16		7		6	7	14.50
	600	729	2	0	0		6		5	9	9
	500	607	7	13	8		5		4	11	3.50
	400	486	1	6	16		4		3	12	22
	300	364	7	0	0		3		2	14	16.50
	200	243	0	13	8		2		1	16	11
	100	121	6	6	16		1		0	18	5.50
	90	109	4	10	0	Drams.	15			17	2,10
	80	97	2	13	8		14			15	22.76
	70	85	0	16	16		13			14	19.42
	60	72	11	0	0		12			13	15.08
	50	60	9	3	8		11			12	12.74
	40	48	7	6	16		10			11	9.40
	30	36	5	10	0		9			10	6.0[illegible]
	20	24	3	13	8		8			9	2.72
	10	12	1	16	16		7			8	23.38
	9	10	11	5	0		6			7	20.04
	8	9	8	13	8		5			6	16.70
	7	8	6	1	16		4			5	13.36
	6	7	3	10	0		3			3	10.02
	5	6	0	18	8		2			2	6.68
	4	4	10	6	16		1			1	3.34
	3	3	7	15	0		[illegible]			0	20.51
	2	2	5	3	8		[illegible]				13.67
	1	1	2	11	16		[illegible]				6.8

The two following examples will be ſufficient to explain theſe two tables, and ſhew their agreement.

Ex. I. *In* 6835 *pounds* 6 *ounces* 9 *pennyweights* 6 *grains Troy. Qu. How much Avoirdupoiſe weight?* (See page 163.)

		Avoirdupoiſe.		
		lb.	oz.	drams.
Pounds troy—	4000	3291	6	13.68
	2000	1645	11	6.84
	800	658	4	9.14
	20	16	7	5.02
	10	8	3	10.51
	5	4	1	13.25
oz.	6		6	9.32
pw.	9			7.90
gr.	6			.22
Anſwer.		5624	10	11.88

Ex. II. *In* 5624 *pounds* 10 *ounces* 12 *drams Avoirdupoiſe, Qu. How much Troy weight?* (See page 164.)

		Troy.			
		lb.	oz.	pw.	gr.
Pounds avoird.	5000	6076	4	13	8
	600	729	2	0	0
	20	24	3	13	8
	4	4	10	6	16
oz.	10		9	2	7
dr.	12			13	15.08
Anſwer.		6835	6	9	6.08

LECT. VI.

Of Pneumatics.

THIS ſcience treats of the nature, weight, preſſure, and ſpring of the air, and the effects ariſing therefrom.

The properties of air.

The air is that thin tranſparent fluid body in which we live and breathe. It encompaſſes the whole earth to a conſiderable height; and, together with the clouds and vapours that float in it, is called the atmoſphere. The air is juſtly reckoned among the number of fluids, becauſe it has all the properties by which a fluid is diſtinguiſhed. For, it yields to the leaſt force impreſſed, its parts are eaſily moved among one another, it preſſes according to its perpendicular height, and its preſſure is every way equal.

That the air is a fluid, conſiſting of ſuch particles as have no coheſion betwixt them, but eaſily glide over one another, and yield to the ſlighteſt impreſſion, appears from that eaſe and freedom with which animals breathe in it, and move through it without any difficulty or ſenſible reſiſtance.

But it differs from all other fluids in the three following particulars. 1. It can be compreſſed into a much leſs ſpace than what it naturally poſſeſſeth, which no other fluid can. 2. It cannot be congealed or fixed, as other fluids may. 3. It is of a different denſity in every part, upward from the earth's ſurface, decreaſing in its weight, bulk for bulk, the higher it riſes; and therefore muſt alſo decreaſe in denſity. 4. It is of an elaſtic

elastic or springy nature, and the force of its spring is equal to its weight.

That air is a body, is evident from its excluding all other bodies out of the space it possesses: for, if a glass jar be plunged with its mouth downward into a vessel of water, there will but very little water get into the jar, because the air of which it is full keeps the water out.

As air is a body, it must needs have gravity or weight: and that it is weighty, is demonstrated by experiment. For, let the air be taken out of a vessel by means of the air-pump, then, having weighed the vessel, let in the air again, and upon weighing it when re-filled with air, it will be found considerably heavier. Thus, a bottle that holds a wine quart, being emptied of air and weighed, is found to be about 17 grains lighter than when the air is let into it again; which shews that a quart of air weighs 17 grains. But a quart of water weighs 14625 grains; this divided by 17, quotes 860 in round numbers; which shews, that water is 860 times as heavy as air near the surface of the earth.

As the air rises above the earth's surface, it grows rarer, and consequently lighter, bulk for bulk. For since it is of an elastic or springy nature, and its lowermost parts are pressed with the weight of all that is above them, it is plain that the air must be more dense or compact at the earth's surface, than at any height above it; and gradually rarer the higher up. For, the density of the air is always as the force that compresseth it: and therefore, the air towards the upper parts of the atmosphere being less pressed than that which is near the earth, it will expand itself, and thereby become thinner than at the earth's surface.

Dr. *Cotes* has demonſtrated, that if altitudes in the air be taken in arithmetical proportion, the rarity of the air will be in geometrical proportion. For inſtance,

At the altitude of	Miles above the ſurface of the earth, the air is	times thinner and lighter than at the earth's ſurface.
7	- - - - - - - - - 4	
14	- - - - - - - - - 16	
21	- - - - - - - - - 64	
28	- - - - - - - - - 256	
35	- - - - - - - - 1024	
42	- - - - - - - - 4096	
49	- - - - - - - 16384	
56	- - - - - - - 65536	
63	- - - - - - 262144	
70	- - - - - 1048576	
77	- - - - - 4194304	
84	- - - 16777216	
91	- - - 67108864	
98	- - - 268435456	
105	- - 1073741824	
112	- - 4294967296	
119	- - 17179869184	
126	- - 68719476736	
133	- - 274877906944	
140	- 1099511627776	

And hence it is eaſy to prove by calculation, that a cubic inch of ſuch air as we breathe, would be ſo much rarefied at the altitude of 500 miles, that it would fill a ſphere equal in diameter to the orbit of Saturn.

The weight or preſſure of the air is exactly determined by the following experiment.

The *Torricellian* experiment.

Take a glaſs tube about three feet long, and open at one end; fill it with quickſilver, and putting your finger upon the open end, turn that end downward, and immerſe it into a ſmall veſſel

veſſel of quickſilver, without letting in any air: then take away your finger, and the quickſilver will remain ſuſpended in the tube $29\frac{1}{2}$ inches above its ſurface in the veſſel; ſometimes more, and at other times leſs, as the weight of the air is varied by winds and other cauſes. That the quickſilver is kept up in the tube by the preſſure of the atmoſphere upon that in the baſon, is evident; for, if the baſon and tube be put under a glaſs, and the air be then taken out of the glaſs, all the quickſilver in the tube will fall down into the baſon; and if the air be let in again, the quickſilver will riſe to the ſame height as before. Therefore the air's preſſure on the ſurface of the earth, is equal to the weight of $29\frac{1}{2}$ inches depth of quickſilver all over the earth's ſurface, at a mean rate.

A ſquare column of quickſilver, $29\frac{1}{2}$ inches high, and one inch thick, weighs juſt 15 pounds, which is equal to the preſſure of air upon every ſquare inch of the earth's ſurface; and 144 times as much, or 2160 pounds, upon every ſquare foot; becauſe a ſquare foot contains 144 ſquare inches. At this rate, a middle-ſized man, whoſe ſurface may be about 14 ſquare feet, ſuſtains a preſſure of 30240 pounds, when the air is of a mean gravity: a preſſure which would be inſupportable, and even fatal to us, were it not equal on every part, and counterbalanced by the ſpring of the air within us, which is diffuſed through the whole body; and re-acts with an equal force againſt the outward preſſure.

Now, ſince the earth's ſurface contains (in round numbers) 200,000,000 ſquare miles, and every ſquare mile 27,878,400 ſquare feet, there muſt be 5,575,680,000,000,000 ſquare

feet

feet on the earth's surface; which multiplied by 2160 pounds (the pressure on each square foot) gives 12,043,468,800,000,000,000 pounds for the pressure or weight of the whole atmosphere.

When the end of a pipe is immersed in water, and the air is taken out of the pipe, the water will rise in it to the height of 33 feet above the surface of the water in which it is immersed; but will go no higher: for it is found, that a common pump will draw water no higher than 33 feet above the surface of the well: and unless the bucket goes within that distance from the well, the water will never get above it. Now as it is the pressure of the atmosphere, on the surface of the water in the well, that causes the water to ascend in the pump, and follow the piston or bucket, when the air above it is lifted up; it is evident, that a column of water 33 feet high, is equal in weight to a column of quicksilver of the same diameter, $29\frac{1}{2}$ inches high; and to as thick a column of air, reaching from the earth's surface to the top of the atmosphere.

The barometer. In serene calm weather, the air has weight enough to support a column of quicksilver 31 inches high; but in tempestuous stormy weather, not above 28 inches. The quicksilver thus supported in a glass tube, is found to be a nice counterbalance to the weight or pressure of the air, and to shew its alterations at different times. And being now generally used to denote the changes in the weight of the air, and of the weather consequent upon them, it is called the *barometer*, or weather-glass.

The pressure of the air being equal on all sides of a body exposed to it, the softest bodies sustain

sustain this pressure without suffering any change in their figure; and so do the most brittle bodies without being broke.

The air is rarefied, or made to swell with heat; and of this property, *wind* is a necessary consequence. For, when any part of the air is heated by the sun, or otherwise, it will swell, and thereby affect the adjacent air: and so, by various degrees of heat in different places, there will arise various winds. The cause of *winds*.

When the air is much heated, it will ascend towards the upper part of the atmosphere, and the adjacent air will rush in to supply its place; and therefore, there will be a stream or current of air from all parts towards the place where the heat is. And hence we see the reason why the air rushes with such force into a glass-house, or towards any place where a great fire is made. And also, why smoke is carried up a chimney, and why the air rushes in at the key-hole of the door, or any small chink, when there is a fire in the room. So we may take it in general, that the air will press towards that part of the world where it is most heated.

Upon this principle, we can easily account for the *trade-winds*, which blow constantly from east to west about the equator. For, when the sun shines perpendicularly on any part of the earth, it will heat the air very much in that part, which air will therefore rise upward, and when the sun withdraws, the adjacent air will rush in to fill its place; and consequently will cause a stream or current of air from all parts towards that which is most heated by the sun. But as the sun, with respect to the earth, moves from east to west, the common course of the air will be that way too; continually pressing after the sun: and therefore, The *trade-winds*.

therefore, at the equator, where the sun shines strongly, there will be a continual wind from the east; but, on the north side, it will incline a little to the north, and on the south side, to the south.

This general course of the wind about the equator, is changed in several places, and upon several accounts; as, 1. By exhalations that rise out of the earth at certain times, and from certain places; in earthquakes, and from volcano's. 2. By the falling of great quantities of rain, causing thereby a sudden condensation or contraction of the air. 3. By burning sands, that often retain the solar heat to a degree incredible to those who have not felt it, causing a more than ordinary rarefaction of the air contiguous to them. 4. By high mountains, which alter the direction of the winds in striking against them. 5. By the declination of the sun towards the north or south, heating the air on the north or south side of the equator.

The monsoons. To these and such like causes is owing, 1. The irregularity and uncertainty of winds in climates distant from the equator, as in most parts of *Europe*. 2. Those periodical winds, called *monsoons*, which in the *Indian* seas blow half a year one way, and the other half another. 3. Those winds which on the coast of *Guiney* and on the western coasts of *America*, blow always from west to east. 4. The sea-breezes which, in hot countries, blow generally from sea to land, in the day-time; and the land breezes, which blow in the night; and, in short, all those storms, hurricanes, whirlwinds, and irregularities, which happen at different times and places.

All common air is impregnated with a certain kind of *vivifying spirit* or quality, which is necessary to continue the lives of animals: and this, in a gallon of air, is sufficient for one man during the space of a minute, and not much longer.

The vivifying spirit in air.

This spirit in air is destroyed by passing through the lungs of animals: and hence it is, that an animal dies soon, after being put under a vessel which admits no fresh air to come to it. This spirit is also in the air which is in water; for fish die when they are excluded from fresh air, as in a pond that is closely frozen over. And the little eggs of insects, stopped up in a glass, do not produce their young, though assisted by a kindly warmth. The seeds also of plants mixed with good earth, and inclosed in a glass, will not grow.

This enlivening quality in air, is also destroyed by the air's passing through fire; particularly charcoal fire, or the flame of sulphur. Hence, smoking chimneys must be very unwholesome, especially if the rooms they are in be small and close.

Air is also vitiated, by remaining closely pent up in any place for a considerable time; or perhaps, by being mixed with malignant steams and particles flowing from the neighbouring bodies; or lastly; by the corruption of the vivifying spirit; as in the holds of ships, in oil-cisterns, or wine-cellars, which have been shut for a considerable time. The air in any of them is sometimes so much vitiated, as to be immediate death to any animal that comes into it.

Air that has lost its vivifying spirit, is called *damp*, not only because it is filled with humid or moist vapours, but because it deadens fire, extin- *Damps.*

extinguishes flame, and destroys life. The dreadful effects of damps are sufficiently known to such as work in mines.

If part of the vivifying spirit of air in any country begins to putrify, the inhabitants of that country will be subject to an epidemical disease, which will continue until the putrefaction is over. And as the putrefying spirit occasions the disease, so if the diseased body contributes towards the putrefying of the air, then the disease will not only be epidemical, but pestilential and contagious.

The atmosphere is the common receptacle of all the effluvia or vapours arising from different bodies; of the steams and smoke of things burnt or melted; the fogs or vapours proceeding from damp watery places; and of the effluvia from sulphureous, nitrous, acid, and alkaline bodies. In short, whatever may be called volatile, rises in the air to greater or less heights, according to its specific gravity.

Fermentations. When the effluvia, which arise from acid and alkaline bodies, meet each other in the air, there will be a strong conflict or *fermentation* between them; which will sometimes be so great, as to produce a fire; then if the effluvia be combustible, the fire will run from one part to another, just as the inflammable matter happens to lie.

Any one may be convinced of this, by mixing an acid and an alkaline fluid together, as the spirit of nitre and oil of cloves; upon the doing of which, a sudden ferment, with a fine flame, will arise; and if the ingredients be very pure and strong, there will be a sudden explosion.

Thunder and lightning. Whoever considers the effects of fermentation, cannot be at a loss to account for the dreadful

readful effects of *thunder* and *lightning*: for the effluvia of sulphureous and nitrous bodies, and others that may rise into the atmosphere, will ferment with each other, and take fire very often of themselves; sometimes by the assistance of the sun's heat.

If the inflammable matter be thin and light, it will rise to the upper part of the atmosphere, where it will flash without doing any harm: but if it be dense, it will lie nearer the surface of the earth, where taking fire, it will explode with a surprizing force, and by its heat rarefy and drive away the air, kill men and cattle, split trees, walls, rocks, &c. and be accompanied with terrible claps of thunder.

The heat of lightning appears to be quite different from that of other fires; for it has been known to run through wood, leather, cloth, &c. without hurting them, while it has broken and melted iron, steel, silver, gold, and other hard bodies. Thus it has melted or burnt asunder a sword, without hurting the scabbard; and money in a man's pocket, without hurting his cloaths: the reason of this seems to be, that the particles of the fire are so fine, as to pass through soft loose bodies without dissolving them; whilst they spend their whole force upon the hard ones.

It is remarkable, that knives and forks which have been struck with lightning have a very strong magnetical virtue for several years after; and I have heard that lightning striking upon the mariner's compass, will sometimes turn it round; and often make it stand the contrary way; or with the north pole towards the south.

Fire-damps. Much of the same kind with lightning, are those explosions, called *fulminating* or *fire-damps*, which

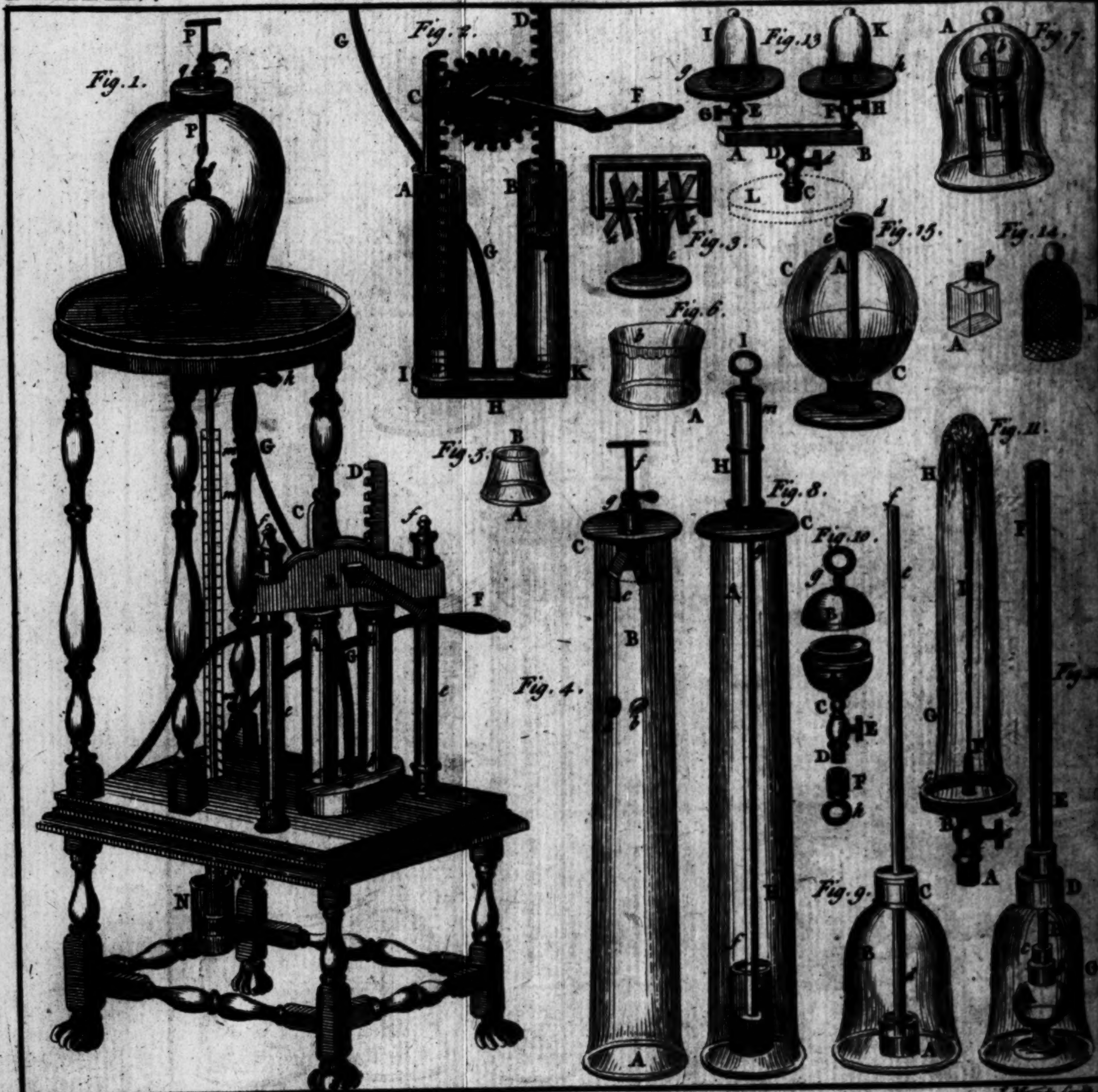
which sometimes happen in mines; and
occasioned by sulphureous and nitrous, o
ther oleaginous particles, rising from the m
and mixing with the air, where they will
fire by the lights which the workmen are ob
to make use of. The fire being kindled
run from one part of the mine to another,
a train of gunpowder, as the combustible m
happens to lie. And as the elasticity of th
is increased by heat, that in the mine will
sequently swell very much, and so, for wan
room, will explode with a greater or less deg
of force, according to the density of the c
bustible vapours. It is sometimes so strong
to blow up the mine; and at other times
weak, that when it has taken fire at the fl
of a candle, it is easily blown out.

Air that will take fire at the flame of a ca
may be produced thus. Having exhaust
receiver of the air-pump, let the air run
through the flame of the oil of turpentine;
remove the cover of the receiver, and holdi
candle to that air, it will take fire, and b
quicker or slower, according to the densi
the oleaginous vapour.

Earthquakes. When such combustible matter, as is abo
mentioned, kindles in the bowels of the ea
where there is little or no vent, it produ
earthquakes, and violent storms or hurrican
wind when it breaks forth into the air.

An artificial earthquake may be made t
Take 10 or 15 pounds of sulphur, and as m
of the filings of iron, and knead them
common water into the consistence of a pa
this being buried in the ground, will, in
10 hours time, burst out in flames, and c

PLATE XIV.



J. Ferguson delin.

J. Mynde sculp.

the earth to tremble all around to a considerable distance.

From this experiment we have a very natural account of the fire of mount *Ætna*, *Vesuvius*, and other volcano's, they being probably set on fire at first by the mixture of such metalline and sulphureous particles.

The *air-pump* being in effect the same as the water-pump, whoever understands the one, will be at no loss to understand the other. PlateXIV. Fig. 1.

Having put a wet leather on the plate *LL* of the air-pump, place the glass receiver *M* upon the leather, so that the hole *i* in the plate may be within the glass. Then, turning the handle *F* backward and forward, the air will be pumped out of the receiver; which will then be held down to the plate by the pressure of the external air, or atmosphere. For, as the handle (Fig. 2.) is turned backwards, it raises the piston *de* in the barrel *BK*, by means of the wheel *F* and rack *Dd*: and, as the piston is leathered so tight as to fit the barrel exactly, no air can get between the piston and barrel; and therefore, all the air above *d* in the barrel is lifted up towards *B*, and a vacuum is made in the barrel from *e* to *b*; upon which, part of the air in the receiver *M* (Fig. 1.) by its spring, rushes through the hole *i*, in the brass plate *LL*, along the pipe *GCG* (which communicates with both barrels by the hollow trunk *IHK* (Fig. 2.) and pushing up the valve *b*, enters into the vacant place *be* of the barrel *BK*. For, wherever the resistance or pressure is taken off, the air will run to that place, if it can find a passage.—Then, as the handle *F* be turned forward, the piston *de* will be depressed in the barrel; and, as the air which had got into the

The *air-pump*.

barrel cannot be pushed back through the valve *b*, it will ascend through a hole in the piston, and escape through the valve at *d*; and be hindered by that valve from returning into the barrel, when the piston is again raised. At the next raising of the piston, a vacuum is again made in the same manner as before, between *b* and *e*; upon which more of the air, which was left in the receiver *M*, gets out thence by its spring, and runs into the barrel *B K*, through the valve *B*. The same thing is to be understood with regard to the other barrel *A I*; and as the handle *F* is turned backwards and forwards, it alternately raises and depresses the pistons in their barrels; always raising one whilst it depresses the other. And, as there is a vacuum made in each barrel when its piston is raised, every particle of air in the receiver *M* pushes out another, by its spring or elasticity, through the hole *i*, and pipe *G G* into the barrels; until at last the air in the receiver comes to be so much dilated, and its spring so far weakened, that it can no longer get through the valves; and then no more can be taken out. Hence, there is no such thing as making a perfect vacuum in the receiver; for the quantity of air taken out at any one stroke, will always be as the density thereof in the receiver: and therefore it is impossible to take it all out, because, supposing the receiver and barrels of equal capacity, there will be always as much left as was taken out at the last turn of the handle.

There is a cock *k* below the pump-plate, which being turned, lets the air into the receiver again; and then the receiver becomes loose, and may be taken off the plate. The barrels are fixed to the frame *E e e* by two screw-nuts *f f*, which

which press down the top-piece *E* upon the barrels: and the hollow trunk *H* (in Fig. 2.) is covered by a box, as *G H* in Fig. 1.

There is a glass tube *lmmmn* open at both ends, and about 34 inches long; the upper end communicating with the hole in the pump-plate, and the lower end immersed in quicksilver at *n* in the vessel *N*. To this tube is fitted a wooden ruler *mm*, called the *gage*, which is divided into inches and parts of an inch, from the bottom at *n* (where it is even with the surface of the quicksilver) and continued up to the top, a little below *l*, to 30 or 31 inches.

As the air is pumped out of the receiver *M*, it is likewise pumped out of the glass tube *lmn*, because that tube opens into the receiver through the pump-plate; and as the tube is gradually emptied of air, the quicksilver in the vessel *N* is forced up into the tube by the pressure of the atmosphere. And if the receiver could be perfectly exhausted of air, the quicksilver would stand as high in the tube, as it does at that time in the barometer: for it is supported by the same power or weight of the atmosphere in both.

The quantity of air exhausted out of the receiver on each turn of the handle, is always proportionable to the ascent of the quicksilver on that turn; and the quantity of air remaining in the receiver, is proportionable to the defect of the height of the quicksilver in the gage, from what it is at that time in the barometer.

I shall now give an account of the experiments made with the air-pump in my lectures; shewing the resistance, weight, and elasticity of the

I. *To shew the resistance of the air.*

1. There is a little machine, consisting of tw mills, *a* and *b*, which are of equal weights, in dependant of each other, and turn equally fr on their axes in the frame. Each mill has fou thin arms or sails, fixed into the axis: those o the mill *a* have their planes at right angles to it axis, and those of *b* have their planes parallel t it. Therefore, as the mill *a* turns round in com mon air, it is but little resisted thereby, becau it's sails cut the air with their thin edges: bu the mill *b* is much resisted, because the broa sides of it's sails move against the air when turns round. In each axle is a pin near th middle of the frame, which goes quite throug the axle, and stands out a little on each side of i upon these pins, the slider *d* may be made to bea and so hinder the mills from going, when th strong spring *c* is set on bend against the opposi ends of the pins.

Fig. 3.

Having set this machine upon the pump plate *L L* (Fig. 1.) draw up the slider *d* to th pins on one side, and set the spring *c* at ben upon the opposite ends of the pins: then pu down the slider *d*, and the spring acting equall strong upon each mill, will set them both a goin with equal forces and velocities: but the mill will run much longer than the mill *b*, because th air makes much less resistance against the edg of its sails, than against the sides of the sai of *b*.

Draw up the slider again, and set the sprin upon the pins as before; then cover the ma chine with the receiver *M* upon the pump plate, and having exhausted the receiver of ai

Fig. 1.

pu

push down the wire *P P* (through the collar of leathers in the neck *q*) upon the ſlider; which will diſengage it from the pins, and allow the mills to turn round by the impulſe of the ſpring: and as there is no air in the receiver to make any ſenſible reſiſtance againſt them, they will both move a conſiderable time longer than they did in the open air; and the moment that one ſtops, the other will do ſo too.—This ſhews that air reſiſts bodies in motion, and that equal bodies meet with different degrees of reſiſtance, according as they preſent greater or leſs ſurfaces to the air, in the planes of their motions.

2. Take off the receiver *M*, and the mills; and having put the guinea *a* and feather *b* upon the braſs flap *c*, turn up the flap, and ſhut it into the notch *d*. Then, putting a wet leather over the top of the tall receiver *AB* (it being open both at top and bottom) cover it with the plate *C*, from which the guinea-and-feather tongs *e d* will then hang within the receiver. This done, pump the air out of the receiver; and then draw up the wire *f* a little, which by a ſquare piece on its lower end will open the tongs *e d*; and the flap falling down as at *c*, the guinea and feather will deſcend with equal velocities in the receiver; and both will fall upon the pump-plate at the ſame inſtant. *N. B.* In this experiment, the obſervers ought not to look at the top, but at the bottom of the receiver; in order to ſee the guinea and feather fall upon the plate: otherwiſe, on account of the quickneſs of their motion, they will eſcape the ſight of the beholders. Fig. 4.

II. *To shew the weight of the air.*

1. Having fitted a brass cap, with a valve tied over it to the mouth of a thin bottle or *Florence* flask, whose contents are exactly known, screw the neck of this cap into the hole *i* of the pump-plate: then, having exhausted the air out of the flask, and taken it off from the pump, let it be suspended at one end of a balance, and nicely counterpoised by weights in the scale at the other end: this done, raise up the valve with a pin, and the air will rush into the flask with an audible noise: during which time, the flask will descend, and pull down that end of the beam. When the nose is over, put as many grains into the scale at the other end as will restore the equilibrium; and they will shew exactly the weight of the quantity of air which has got into the flask, and filled it. If the flask holds an exact quart, it will be found, that 17 grains will restore the equipoise of the balance, when the quicksilver stands at $29\frac{1}{2}$ inches in the barometer: which shews, that when the air is at a mean rate of density, a quart of it weighs 17 grains: it weighs more when the quicksilver stands higher; and less when it stands lower.

2. Place the small receiver O (Fig. 1.) over the hole *i* in the pump plate, and upon exhausting the air, the receiver will be fixed down to the plate by the pressure of the air on its outside, which is left to act alone, without any air in the receiver to act against it: and this pressure will be equal to as many times 15 pounds, as there are square inches in that part of the plate which the receiver covers; which will hold down the receiver so fast, that it cannot be got off, until the

the air be let into it by turning the cock *k*; and then it becomes loose.

3. Set the little glass *AB* (which is open at both ends) over the hole *i* upon the pump-plate *LL*, and put your hand close upon the top of it at *B*: then upon exhausting the air out of the glass, you will find your hand pressed down with a great weight upon it; so that you can hardly release it, until the air be readmitted into the glass by turning the cock *k*; which air, by acting as strongly upward against the hand as the external air acted in pressing it downward, will release the hand from its confinement. Fig. 5.

4. Having tied a piece of wet bladder *b* over the open top of the glass *A* (which is also open at bottom) set it to dry, and then the bladder will be tight like a drum. Then place the open end *A* upon the pump-plate, over the hole *i*, and begin to exhaust the air out of the glass. As the air is exhausting, its spring in the glass will be weakened, and give way to the pressure of the outward air on the bladder, which, as it is pressed down, will put on a spherical concave figure, which will grow deeper and deeper, until the strength of the bladder be overcome by the weight of the air; and then it will break with a report as loud as that of a gun.—If a flat piece of glass be laid upon the open top of this receiver, and joined to it by a flat ring of wet leather between them; upon pumping the air out of the receiver, the pressure of the outward air upon the flat glass will break it all to pieces. Fig. 6.

5. Immerse the neck *c d* of the hollow glass ball *e b* in water, contained in the phial *a a*; then set it upon the pump-plate, and cover it and the hole *i* with the close receiver *A*; and then begin Fig. 7.

 to

to pump out the air. As the air goes out of the receiver by its ſpring, it will alſo by the ſame means go out of the hollow ball *e b*, through the neck *d c*, and riſe up in bubles to the ſurface of the water in the phial; from whence it will make its way, with the reſt of the air in the receiver, through the air-pipe *G G* and valves *a* and *b*, into the open air. When it has done bubbling in the phial, the ball is ſufficiently exhauſted; and then, upon turning the cock *k*, the air will get into the receiver, and preſs ſo upon the ſurface of the water in the phial, as to force the water up into the ball in a jet, through the neck *cd*; and will fill the ball almoſt full of water. The reaſon why the ball is not quite filled, is becauſe all the air could not be taken out of it; and the ſmall quantity that was left in, and had expanded itſelf ſo as to fill the whole ball, is now condenſed into the ſame ſtate as the outward air, and remains in a ſmall bubble at the top of the ball; and ſo keeps the water from filling that part of the ball.

Fig. 8. 6. Pour ſome quickſilver into the jar *D*, and ſet it on the pump-plate near the hole *i*; then ſet on the tall open receiver *A B*, ſo as to be over the jar and hole; and cover the receiver with the braſs plate *C*. Screw the open glaſs tube *fg* (which has a braſs top on it at *h*) into the ſyringe *H*, and putting the tube through a hole in the middle of the plate, ſo as to immerſe the lower end of the tube *e* in the quickſilver at *D*, ſcrew the end *b* of the ſyringe into the plate. This done, draw up the piſton in the ſyringe by the ring *I*, which will make a vacuum in the ſyringe, below the piſton; and as the upper end of the tube opens into the ſyringe, the air will be dilated in the tube, becauſe part of it, by its ſpring, gets

gets up into the ſyringe; and the ſpring of the undilated air in the receiver acting upon the ſurface of the quickſilver in the jar, will force part of it up into the tube: for the quickſilver will follow the piſton in the ſyringe, in the ſame way, and for the ſame reaſon, that water follows the piſton of a common pump when it is raiſed in the pump-barrel; and this, according to ſome, is done by ſuction. But to refute that erroneous notion, let the air be pumped out of the receiver *AB*, and then all the quickſilver in the tube will fall down by its own weight into the jar; and cannot be again raiſed one hair's breadth in the tube by working the ſyringe: which ſhews that ſuction had no hand in raiſing the quickſilver; and, to prove that it is done by preſſure, let the air into the receiver by the cock *k* (Fig. 1.) and its action upon the ſurface of the quickſilver in the jar will raiſe it up into the tube, although the piſton of the ſyringe continues motionleſs.—If the tube be about 32 or 33 inches high, the quickſilver will riſe in it very near as high as it ſtands at that time in the barometer. And, if the ſyringe has a ſmall hole, as *m*, near the top of it, and the piſton be drawn up above that hole, the air will ruſh through the hole into the ſyringe and tube, and the quickſilver will immediately fall down into the jar. If this part of the apparatus be air-tight, the quickſilver may be pumped up into the tube to the ſame height that it ſtands in the barometer; but it will go no higher, becauſe then the weight of the column in the tube is the ſame as the weight of a column of air of the ſame thickneſs with the quickſilver, and reaching from the earth to the top of the atmoſphere.

7. Hav-

Fig. 9. 7. Having placed the jar *A*, with some quick-silver in it, on the pump-plate, as in the last experiment, cover it with the receiver *B*; then push the open end of the glass tube *d e* through the collar of leathers in the brass neck *C* (which it fits so as to be air-tight) almost down to the quicksilver in the jar. Then exhaust the air out of the receiver, and it will also come out of the tube, because the tube is close at top. When the gauge *m m* shews that the receiver is well exhausted, push down the tube, so as to immerse its lower end into the quicksilver in the jar. Now, although the tube be exhausted of air, none of the quicksilver will rise into it, because there is no air left in the receiver to press upon its surface in the jar. But let the air into the receiver by the cock *k*, and the quicksilver will immediately rise in the tube; and stand as high in it, as it was pumped up in the last experiment.

Both these experiments shew, that the quick-silver is supported in the barometer by the pressure of the air on its surface in the box, in which the open end of the tube is placed. And that the more dense and heavy the air is, the higher does the quicksilver rise; and, on the contrary, the thinner and lighter the air is, the more will the quicksilver fall. For if the handle *F* be turned ever so little, it takes some air out of the receiver, by raising one or other of the pistons in its barrel; and consequently, that which remains in the receiver is so much the rarer, and has so much the less spring and weight; and thereupon, the quicksilver falls a little in the tube: but upon turning the cock, and re-admitting the air into the receiver, it becomes as weighty as before, and the quick-silver rises again to the same height.

height.—Thus we see the reason why the quicksilver in the barometer falls before rain or snow, and rises before fair weather; for, in the former case, the air is too thin and light to bear up the vapours, and in the latter, too dense and heavy to let them fall.

N. B. In all mercurial experiments with the air-pump, a short pipe must be screwed into the hole *i*, so as to rise about an inch above the plate, to prevent the quicksilver from getting into the air-pipe and barrels, in case any of it should be accidentally spilt over the jar: for if it once gets into the pipes or barrels, it spoils them, by loosening the solder, and corroding the brass.

8. Take the tube out of the receiver, and put one end of a bit of dry hazel branch, about an inch long, tight into the hole, and the other end tight into a hole quite through the bottom of a small wooden cup: then pour some quicksilver into the cup, and exhaust the receiver of air, and the pressure of the outward air, on the surface of the quicksilver, will force it through the pores of the hazel, from whence it will descend in a beautiful shower into a cup placed under the receiver to catch it.

9. Put a wire through the collar of leathers in the top of the receiver, and fix a bit of dry wood on the end of the wire within the receiver; then exhaust the air, and push the wire down, so as to immerse the wood into a jar of quicksilver on the pump-plate; this done, let in the air, and upon taking the wood out of the jar, and splitting it, its pores will be found full of quicksilver, which the force of the air, upon being let into the receiver, drove into the wood.

10. Join the two brass hemispherical cups *A* and *B* together, with a wet leather between them, having Fig. 10.

ing a hole in the middle of it; then ſcrew the end *D* of the pipe *C D* into the plate of the pump at *i*, and turn the cock *E*, ſo as the pipe may be open all the way into the cavity of the hemiſpheres: then exhauſt the air out of them, and turn the cock a quarter round, which will ſhut the pipe *C D*, and keep out the air. This done, unſcrew the pipe at *D* from the pump; and ſcrew the piece *F b* upon it at *D*; and let two ſtrong men try to pull the hemiſpheres aſunder by the rings *g* and *b*, which they will find hard to do: for if the diameter of the hemiſpheres be four inches, they will be preſſed together by the external air with a force equal to 188 pounds. And to ſhew that it is the preſſure of the air that keeps them together, hang them by either of the rings upon the hook *P* of the wire in the receiver *M* (Fig. 1.) and upon exhauſting the air out of the receiver, they will fall aſunder of themſelves.

11. Place a ſmall receiver *O* (Fig. 1.) near the hole *i* on the pump-plate, and cover both it and the hole with the receiver *M*; and turn the wire ſo by the top *P*, that its hook may take hold of the little receiver by a ring at its top, allowing that receiver to ſtand with its own weight on the plate. Then, upon working the pump, the air will come out of both receivers; but the large one *M* will be forcibly held down to the pump by the preſſure of the external air; whilſt the ſmall one *O*, having no air to preſs upon it, will continue looſe, and may be drawn up and let down at pleaſure, by the wire *P P*. But, upon letting it quite down to the plate, and admitting the air into the receiver *M*, by the cock *k*, the air will preſs ſo ſtrongly upon the ſmall receiver *O*, as to fix it down to the plate; and at the

the ſame time, by counterbalancing the outward preſſure on the large receiver *M*, it will become looſe. This experiment evidently ſhews, that the receivers are held down by preſſure, and not by ſuction, for the internal receiver continued looſe whilſt the operator was pumping, and the external one was held down; but the former became faſt immediately by letting in the air upon it.

12. Screw the end *A* of the braſs pipe *ABF* into the hole of the pump-plate, and turn the cock *e* until the pipe be open; then put a wet leather upon the plate *c d*, which is fixed on the pipe and cover it with the tall receiver *GH*, which is cloſe at top: then exhauſt the air out of the receiver, and turn the cock *e* to keep it out; which done, unſcrew the pipe from the pump, and ſet its end *A* into a baſon of water, and turn the cock *e* to open the pipe; on which, as there is no air in the receiver, the preſſure of the atmoſphere on the water in the baſon will drive the water forcibly through the pipe, and make it play up in a jet to the top of the receiver. Fig. 11.

13. Set the ſquare phial *A* (Fig. 14.) upon the pump-plate, and having covered it with the wire cage *B*, put a cloſe receiver over it, and exhauſt the air out of the receiver; in doing of which, the air will alſo make its way out of the phial through a ſmall hole in its neck under the valve *b*. When the air is exhauſted, turn the cock below the plate, to re-admit the air into the receiver; and as it cannot get into the phial again, becauſe of the valve, the phial will be broke into ſome thouſands of pieces by the preſſure of the air upon it. Had the phial been of a round form, it would have ſuſtained this

preſſure

pressure like an arch, without breaking; but as its sides are flat, it cannot.

To shew the elasticity or spring of the air.

14. Tie up a very small quantity of air in a bladder, and put it under a receiver; then exhaust the air out of the receiver; and the small quantity which is confined in the bladder (having nothing to act against it) will expand itself so by the force of its spring, as to fill the bladder as full as it could be blown of common air. But upon letting the air into the receiver again, it will overpower the air in the bladder, and press its sides almost close together.

15. If the bladder so tied up be put into a wooden box, and have 20 or 30 pounds weight of lead put upon it in the box, and the box be covered with a close receiver; upon exhausting the air out of the receiver, that air which is confined in the blader will expand itself so, as to raise up all the lead by the force of its spring.

Fig. 7. 16. Take the glass ball mentioned in the fifth experiment, which was left full of water all but a small bubble of air at top, and having set it with its neck downward into the empty phial *a a*, and covered it with a close receiver, exhaust the air out of the receiver, and the small bubble of air in the top of the ball will expand itself, so as to force all the water out of the ball into the phial.

Fig. 11. 17. Screw the pipe *A B* into the pump-plate, place the tall receiver *G H* upon the plate *c d*, as in the twelfth experiment, and exhaust the air out of the receiver; then, turn the cock *e* to keep out the air, unscrew the pipe from the pump, and screw it into the mouth of the copper

vessel

veſſel CC (Fig. 15.) the veſſel having firſt been about half filled with water. Then open the cock e (Fig. 11.) and the ſpring of the air which is confined in the copper veſſel will force the water up through the pipe AB in a jet into the exhauſted receiver, as ſtrongly as it did by its preſſure on the ſurface of the water in a baſon, in the twelfth experiment.

18. If a fowl, a cat, rat, mouſe, or bird, be put under a receiver, and the air be exhauſted, the animal will be at firſt oppreſſed as with a great weight, then grow convulſed, and at laſt expire in all the agonies of a moſt bitter and cruel death. But as this experiment is too ſhocking to every ſpectator who has the leaſt degree of humanity, we ſubſtitute a machine called the *lungs-glaſs* in place of the animal.

19. If a butterfly be ſuſpended in a receiver, by a fine thread tied to one of its horns, it will fly about in the receiver, as long as the receiver continues full of air; but if the air be exhauſted, though the animal will not die, and will continue to flutter its wings, it cannot remove itſelf from the place where it hangs in the middle of the receiver, until the air be let in again, and then the animal will fly about as before.

20. Pour ſome quickſilver into the ſmall bottle A, and ſcrew the braſs collar c of the tube BC into the braſs neck b of the bottle, and the lower end of the tube will be immerſed into the quickſilver, ſo that the air above the quickſilver in the bottle will be confined there, becauſe it cannot get out about the joinings, nor can it be drawn out through the quickſilver into the tube. This tube is alſo open at top, and is to be covered with the receiver G and large tube EF, which tube is fixed by braſs collars to the receiver, and is cloſe Fig. 12.

at

at the top. This preparation being made, exhaust the air both out of the receiver and its tube; and the air will by the same means be exhausted out of the inner tube *B C*, through its open top at *C*; and as the receiver and tubes are exhausting, the air that is confined in the glass bottle *A* will press so by its spring upon the surface of the quicksilver, as to force it up in the inner tube as high as it was raised in the ninth experiment by the pressure of the atmosphere: which demonstrates that the spring of the air is equivalent to its weight.

Fig. 13. 21. Screw the end *C* of the pipe *C D* into the hole of the pump-plate, and turn all the three cocks *d*, *G*, and *H*, so as to open the communications between all the three pipes *E*, *F*, *DC*, and the hollow trunk *A B*. Then, cover the plates *g* and *b* with wet leathers, which have holes in their middle where the pipes open into the plates; and place the close receiver *I* upon the plate *g*: this done, shut the pipe *F* by turning the cock *H*, and exhaust the air out of the receiver *I*. Then, turn the cock *d* to shut out the air, unscrew the machine from the pump, and having screwed it to the wooden foot *L*, put the receiver *K* upon the plate *b*; this receiver will continue loose on the plate as long as it keeps full of air; which it will do until the cock *H* be turned to open the communication between the pipes *F* and *E*, through the trunk *A B*; and then the air in the receiver *K*, having nothing to act against its spring, will run from *K* into *I*, until it be so divided between these receivers, as to be of equal density in both; and then they will be held down with equal forces to their plates by the pressure of the atmosphere; though each receiver will then be kept down but with one half

half of preſſure upon it, that the receiver *I* had, when it was exhauſted of air; becauſe it has now one half of the common air in it which filled the receiver *K* when it was ſet upon the plate; and therefore, a force equal to half the force of the ſpring of common air, will act within the receivers againſt the whole preſſure of the common air upon their outſides. This is called transferring the air out of one veſſel into another.

22. Put a cork into the ſquare phial *A*, and fix it in with wax or cement; put the phial upon the pump-plate with the wire cage *B* over it, and cover the cage with a cloſe receiver. Then, exhauſt the air out of the receiver, and the air that was corked up in the phial will break the phial outwards by the force of its ſpring, becauſe there is no air left on the outſide of the phial to act againſt the air within it. Fig. 14.

22. Put a ſhrivelled apple under a cloſe receiver, and exhauſt the air; then the ſpring of the air within the apple will plump it out, ſo as to cauſe all the wrinkles diſappear; but upon letting the air into the receiver again, to preſs upon the apple, it will inſtantly return to its former decayed and ſhrivelled ſtate.

23. Take a freſh egg, and cut off a little of the ſhell and film from its ſmalleſt end, then put the egg under a receiver, and pump out the air; upon which, all the contents in the egg will be forced out into the receiver, by the expanſion of a ſmall bubble of air contained in the great end, between the ſhell and film.

24. Put ſome warm beer in a glaſs, and having ſet it on the pump, cover it with a cloſe receiver, and then exhauſt the air. Whilſt this is doing, and thereby the preſſure more and more

taken off from the beer in the glaſs, the air therein will expand itſelf, and riſe up in innumerable bubbles to the ſurface of the beer; and from thence it will be taken away with the other air in the receiver. When the receiver is nearly exhauſted, the air in the beer, which could not diſentangle itſelf quick enough to get off with the reſt, will now expand itſelf ſo, as to cauſe the beer to have all the appearance of boiling; and the greateſt part of it will go over the glaſs.

25. Put ſome warm water in a glaſs, and put a bit of dry wainſcot or other wood into the water. Then, cover the glaſs with a cloſe receiver, and exhauſt the air; upon which, the air in the wood having liberty to expand itſelf, will come out plentifully, and make all the water to bubble about the wood, eſpecially about the ends, becauſe the pores lie lengthwiſe. A cubic inch of dry wainſcot has ſo much air in it, that it will continue bubbling for near half an hour together.

Miſcellaneous experiments.

26. Screw the ſyringe *H* (Fig. 8.) to a piece of lead that weighs one pound at leaſt; and, holding the lead in one hand, pull up the piſton in the ſyringe with the other; then, quitting hold of the lead, the air will puſh it upward, and drive back the ſyringe upon the piſton. The reaſon of this is, that the drawing up of the piſton makes a vacuum in the ſyringe, and the air, which preſſes every way equally, having nothing to reſiſt its preſſure upward, the lead is thereby preſſed upward, contrary to its natural tendency by gravity. If the ſyringe, ſo loaded, be

be hung in a receiver, and the air be exhausted, the syringe and lead will descend upon the piston-rod by their natural gravity; and, upon admitting the air into the receiver, they will be drove upward again, until the piston be at the very bottom of the syringe.

27. Let a large piece of cork be suspended by a thread at one end of a balance, and counterpoised by a leaden weight, suspended in the same manner, at the other. Let this balance be hung to the inside of the top of a large receiver; which being set on the pump, and the air exhausted, the cork will preponderate, and shew itself to be heavier than the lead; but upon letting in the air again, the equilibrium will be restored. The reason of this is, that since the air is a fluid, and all bodies lose as much of their absolute weight in it, as is equal to the weight of their bulk of the fluid, the cork being the larger body, loses more of its real weight than the lead does; and therefore must in fact be heavier, to balance it under the disadvantage of losing some of its weight: which disadvantage being taken off by removing the air, the bodies then gravitate according to their real quantities of matter, and the cork, which balanced the lead in air, shews itself to be heavier when in *vacuo*.

28. Set a lighted candle upon the pump, and cover it with a tall receiver. If the receiver holds a gallon, the candle will burn a minute; and then, after having gradually decayed from the first instant, it will go out: which shews, that a constant supply of fresh air is necessary to feed flame; and so it also is for animal life. For a bird kept under a close receiver will soon die, although no air be pumped out; and it is found

found that, in the diving-bell, a gallon of air is sufficient only for one minute for a man to breathe in.

The moment when the candle goes out, the smoke will be seen to ascend to the top of the receiver, and there it will form a sort of cloud: but upon exhausting the air, the smoke will fall down to the bottom of the receiver, and leave it as clear at the top as it was before it was set upon the pump. This shews, that smoke does not ascend on account of its being positively light, but because it is lighter than air; and its falling to the bottom when the air was taken away, shews, that it is not destitute of weight. So most sorts of wood ascend or swim in water; and yet there are none who doubt of the wood's having gravity or weight.

29. Set a receiver, which is open at top, upon the air-pump, and cover it with a brass plate, and wet leather; and having exhausted it of air, let the air in again at top through an iron pipe, making it pass through a charcoal flame at the end of the pipe; and when the receiver is full of that air, lift up the cover, and let down a mouse or bird into the receiver, and the burnt air will immediately kill it. If a candle be let down into the air, it will go out directly; but, by letting it down gently, it will purify the air so far as it goes; and so, by letting it down more and more, all the air in the receiver will be purified.

30. Set a bell upon a cushion on the pump-plate, and cover it with a receiver; then shake the pump to make the clapper strike against the bell, and the sound will be very well heard: but, exhaust the receiver of air, and then, if the clapper be made to strike ever so hard against the

the bell, it will make no ſound at all; which ſhews, that air is abſolutely neceſſary for the propagation of ſound.

31. Let a candle be placed on one ſide of a receiver, and viewed through the receiver at ſome diſtance; then, as ſoon as the air begins to be exhauſted, the receiver will be filled with vapours which riſe from the wet leather, by the ſpring of the air in it; and the light of the candle being refracted through that medium of vapours, will have the appearance of circles of various colours, of a faint reſemblance to thoſe in the rain-bow.

The air-pump was invented by *Otho Guerick* of *Magdeburg*, but was much improved by Mr. *Boyle*, to whom we are indebted for our greateſt part of the knowledge of the wonderful properties of the air, demonſtrated in the above experiments.

The elaſtic air which is contained in many bodies, and is kept in them by the weight of the atmoſphere, may be got out of them either by boiling, or by the air-pump, as ſhewn in the 25th experiment: but the fixed air, which is by much the greater quantity, cannot be got out but by diſtillation, fermentation, or putrefaction.

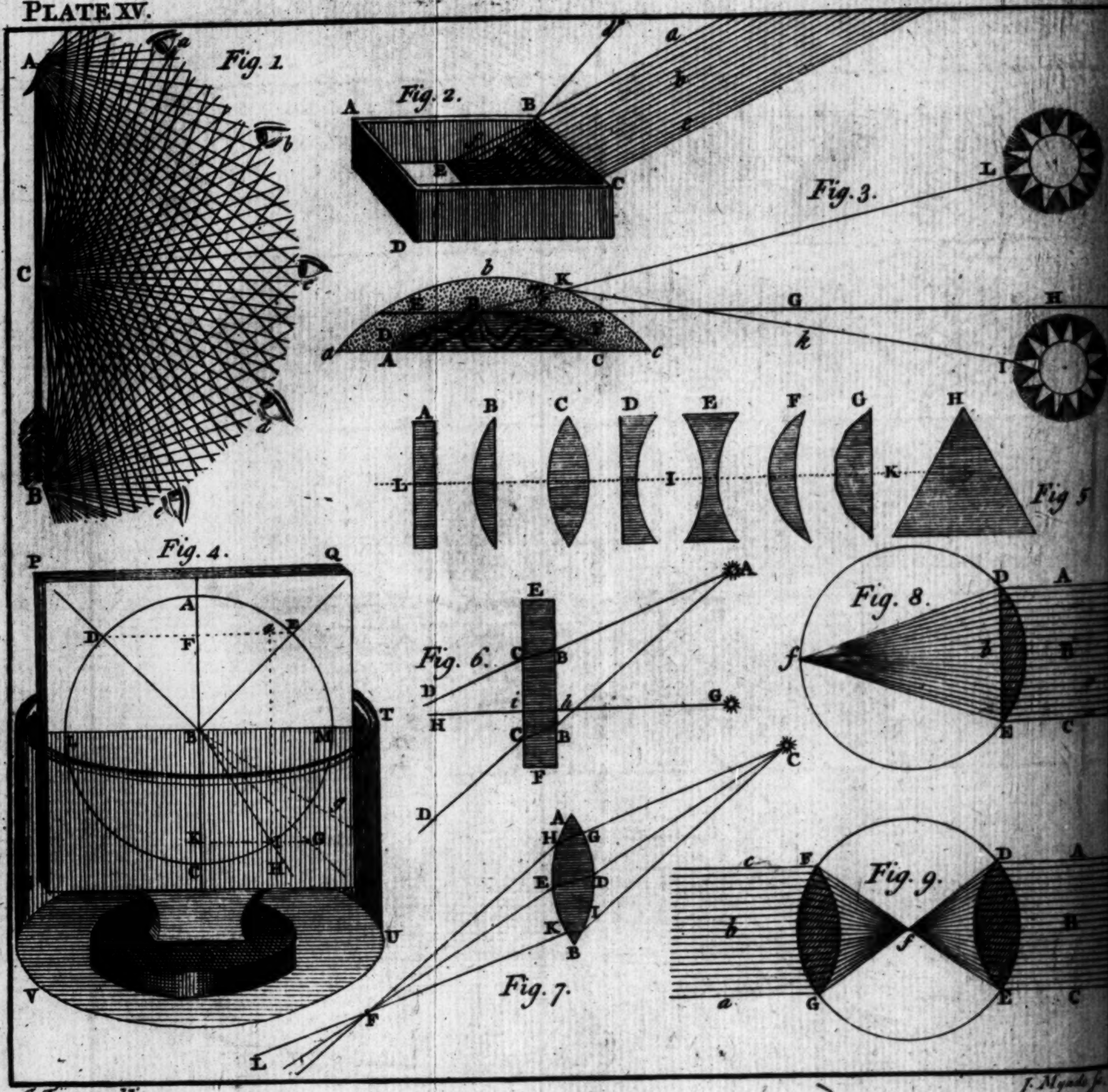
If fixed air did not come out of bodies with difficulty, and ſpend ſome time in extricating itſelf from them, it would tear them to pieces. Trees would be rent by the change of air from a fixt, to an elaſtic ſtate, and animals would be burſt in pieces by the exploſion of air in their food.

Dr. *Hales* found by experiment, that the air in apples is ſo much condenſed, that if it were let out into the common air, it would fill a ſpace

48 times as great as the bulk of the apples them-selves; so that its pressure outwards was equal to 11776 lb. and, in a cubic inch of oak, 19860 lb. against its sides. So that if the air was let loose at once in these substances, they would tear every thing to pieces about them with a force superior to that of gunpowder. Hence, in eating apples, it is well that they part with the air by degrees, as they are chewed, and ferment in the stomach, otherwise, an apple would be immediate death to him who eats it.

The mixing of some substances with others, will release the air from them, all of a sudden; which may be attended with very great danger. Of this we have a remarkable instance in an experiment made by Dr. *Slare*; who having put half a dram of oil of carraway-seeds into one glass, and a dram of compound spirit of nitre in another, covered them both on the air-pump with a receiver six inches wide, and eight inches deep, and then exhausted the air, and continued pumping until all that could possibly be got both out of the receiver, and out of the two fluids, was extricated: then, by a particular contrivance from the top of the receiver, he mixed the fluids together; upon which they produced such a prodigious quantity of air, as instantly blew up the receiver, although it was pressed down by the atmosphere with upwards of 400 pound weight.

PLATE XV.



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LECT. VIII.

Of Optics.

LIGHT consists of an inconceivably great number of particles flowing from a luminous body in all manner of directions; and these particles are so small, as to surpass all human comprehension.

That the number of particles of light is inconceivably great, appears from the light of a candle; which, if there be no obstacle in the way to obstruct the passage of its rays, will fill all the space within two miles of the candle every way, with luminous particles, before it has lost the least sensible part of its substance.

A ray of light is a continued stream of these particles, flowing from any visible body in a straight line: and that the particles themselves are incomprehensibly small, is manifest from the following experiment. Make a small pin-hole in a piece of black paper, and hold the paper upright on a table facing a row of candles standing by one another; then place a sheet of pasteboard at a little distance behind the paper, and some of the rays which flow from all the candles through the hole in the paper, will form as many specks of light on the pasteboard, as there are candles on the table before the plate: each speck being as distinct and clear, as if there was only one speck from one single candle: which shews, that the particles of light are exceedingly small, otherwise they could not pass through the hole from so many different candles without confusion.—Dr. *Niewentyt* has computed, that there flows more than 6,000,000,000,000 times as

The amazing smallness of the particles of light.

many particles of light from a candle in one second of time, as there are grains of sand in the whole earth, supposing each cubic inch of it to contain 1,000,000.

These particles, by falling directly upon our eyes, excite in our minds the idea of light. And when they fall upon bodies, and are thereby reflected to our eyes, they excite in us the ideas of these bodies. And as every point of a visible body reflects the rays of light in all manner of directions, every point will be visible in every part to which the light is reflected from it. Thus the object *A C B* is visible to an eye in any part where the rays *A a*, *A b*, *A c*, *A d*, *A e*, *B a*, *B b*, *B c*, *B d*, *B e*, and *C a*, *C b*, *C c*, *C d*, *C e*, come. Here we have shewn the rays as if they were only reflected from the ends *A* and *B*, and from the middle point *C* of the object; every other point being supposed to reflect rays in the same manner. So that wherever a spectator is placed with regard to the body, every point of that part of the surface which is towards him will be visible, when no intervening object stops the passage of the light.

Plate XV. Fig. 1.

Reflected light.

Since no object can be seen through the bore of a bended pipe, it is evident that the rays of light move in straight lines, whilst there is nothing to refract or turn them out of their rectilineal course.

Whilst the rays of light continue in any * medium of an uniform density, they are straight; but when they pass obliquely out of one medium into another, which is either more dense or more rare,

* Any thing through which the rays of light can pass, is called a medium; as air, water, glass, diamond, or even a vacuum.

rare, they are refracted towards the denser medium: and this refraction is more or less, as the rays fall more or less obliquely on the refracting surface which divides the mediums.

To prove this by experiment, set the empty vessel *ABCD* into any place where the sun shines obliquely, and observe the part where the shadow of the edge *BC* falls on the bottom of the vessel at *E*; then fill the vessel with water, and the shadow will reach no farther than *e*; which shews, that the ray *aBE*, which came straight in the open air, just over the edge of the vessel at *B* to its bottom at *E*, is refracted by falling obliquely on the surface of the water at *B*; and instead of going on in the rectilineal direction *aBE*, it is bent downward in the water from *B* to *e*; the whole bend being at the surface of the water: and so of all the other rays *abc*.

Fig. 2.

Refracted light.

If a stick be laid over the vessel, and the sun's rays be reflected from a glass perpendicularly into the vessel, the shadow of the stick will fall upon the same part of the bottom, whether the vessel be empty or full; which shews, that the rays of light are not refracted when they fall perpendicularly on the surface of any medium.

The rays of light are as much refracted by passing out of water into air, as by passing out of air into water. Thus, if a ray of light flows from the point *e*, under water, in the direction *eB*; when it comes to the surface of the water at *B*, it will not go on thence in the rectilineal course *Bd*, but will be refracted into the line *Ba*. Therefore,

To an eye at *e* looking through a plane glass in the bottom of the empty vessel, the point *a* cannot be seen, because the side *Bc* of the vessel inter-

interposes; and the point *d* will just be seen over the edge of the vessel at *B*. But if the vessel be filled with water, the point *a* will be seen from *e*; and will appear as at *d*, elevated in the direction of the ray *e B* *.

The days are made longer by the refraction of the sun's rays.

The time of sun-rising or setting, supposing its rays suffered no refraction, is easily found by calculation. But observation proves that the sun rises sooner, and sets later every day than the calculated time; the reason of which is plain, from what was said immediately above. For, though the sun's rays do not come part of the way to us through water, yet they do through the air or atmosphere, which being a grosser medium than the free space between the sun and the top of the atmosphere, the rays, by entering obliquely into the atmosphere, are there refracted; and thence bent down to the earth. And although there are many places of the earth to which the sun is vertical at noon, and consequently his rays can suffer no refraction at that time, because they come perpendicularly through the atmosphere; yet there is no place to which the sun's rays do not fall obliquely on the top of the atmosphere, at his rising and setting; and consequently, no clear day in which the sun will not be visible before he rises in the horizon, and after he sets in it: and the longer or shorter, as the atmosphere is more or less replete with vapours. For, let *ABC* be part of the earth's surface, *DEF* the atmosphere that covers it,

Fig. 3.

* Hence a piece of money lying at *e*, in the bottom of an empty vessel, cannot be seen by an eye at *a*, because the edge of the vessel intervenes; but let the vessel be filled with water, and the ray *ea* being then refracted at *B*, will strike the eye at *a*, and so render the money visible, which will appear as if it were raised up to *f* in the line *aBf*.

and

nd *EBGH* the ſenſible horizon of an obſerver
t *B.* As every point of the ſun's ſurface ſends
ut rays of light in all manner of directions,
ome of his rays will conſtantly fall upon, and
nlighten, ſome half of the atmoſphere; and
herefore, when the ſun is at *I*, below the ho-
izon *H*, thoſe rays which go on in the free ſpace
IkK preſerve a rectilineal courſe until they fall
pon the top of the atmoſphere; and thoſe
which fall ſo about *K*, are refracted at their
ntrance into the atmoſphere, and bent down
n the line *K m B*, to the obſerver's place at *B*:
nd therefore, to him, the ſun will appear at *L*,
n the direction of the ray *B m K*, above the hori-
on *BGH*, when he is really below it at *I*.

The angle contained between a ray of light,
nd a perpendicular to the refracting ſurface, is
alled *the angle of incidence*; and the angle con-
ained between the ſame perpendicular, and the
ame ray after refraction, is called *the angle of
efraction*. Thus, let *LBM* be the refracting
urface of a medium (ſuppoſe water) and *ABC*
perpendicular to that ſurface; let *DB* be a
ay of light, going out of air into water at *B*,
nd therein refracted in the line *BH*; the angle
ABD, is the angle of incidence, of which *DF*
the ſine; and the angle *KBH* is the angle of
fraction, whoſe ſine is *KI*.

Angle of incidence.

Fig. 4. *Angle of refraction.*

When the refracting medium is water, the
ne of the angle of incidence is to the ſine of
e angle of refraction, as 4 to 3; which is con-
rmed by the following experiment, taken from
octor SMITH's Optics.

Deſcribe the circle *DAEC* on a plane ſquare
oard, and croſs it at right angles with the
raight lines *ABC*, and *LBM*; then, from
e interſection *A*, with any opening of the com-
paſſes,

passes, set off the equal arcs $A\,D$ and $A\,E$, an
draw the right line $D\,F\,E$: then, taking F
which is three quarters of the length $F\,E$, fro
the point a, draw $a\,I$ parallel to $A\,B\,K$, an
join $K\,I$, parallel to $B\,M$: so $K\,I$ will be equ
to three quarters of $F\,E$ or of $D\,F$. This don
fix the board upright upon the leaden pedest
O, and stick three pins perpendicularly into th
board, at the points D, B, and I: then set th
board upright into the vessel $T\,U\,V$, and fill u
the vessel with water to the line $L\,B\,M$. Whe
the water has settled, look along the line $D\,B$
so as you may see the head of the pin B over th
head of the pin D; and the pin I will appear i
the same right line produced to G, for its hea
will be seen just over the head of the pin at B
which shews that the ray $I\,B$, coming from th
pin at I, is so refracted at B, as to proceed fro
thence in the line $B\,D$ to the eye of the observe
the same as it would do from any point G in th
right line $D\,B\,G$, if there were no water in th
vessel: and also shews that $K\,I$, the sine of re
fraction in water, is to $D\,F$, the sine of inci
dence in air, as 3 to 4 *.

Angle of incidence.

Fig. 4. Angle of refraction.

Hence, if $D\,B\,H$ were a crooked stick p
obliquely into the water, it would appear
straight one, as $D\,B\,G$. Therefore, as the li
$B\,H$ appears at $B\,G$, so the line $B\,G$ will appe
at $B\,g$; and consequently, a straight stick $D\,B$
put obliquely into water, will seem bent at th
surface of the water in B, and crooked,
$D\,B\,g$.

When a ray of light passes out of air in
glass, the sine of incidence is to the sine of r

* This is strictly true of the red rays only, for the oth coloured rays are differently refracted; but the difference so small, that it need not be considered in this place.

fraction

fraction, as 3 to 2; and when out of air into a diamond, as 5 to 2.

Glass may be ground into eight different shapes at least, for optical purposes, viz. Fig. 5.

1. A *plane glass*, which is flat on both sides, and of equal thickness in all its parts, as *A*.

2. A *plano-convex*, which is flat on one side, and convex on the other, as *B*. Lenses.

3. A *double convex*, which is convex on both sides, as *C*.

4. A *plano-concave*, which is flat on one side, and concave on the other, as *D*.

5. A *double concave*, which is concave on both sides, as *E*.

6. A *meniscus*, which is concave on one side, and convex on the other, as *F*.

7. A *flat plano-convex*, whose convex side is ground into several little flat surfaces, as *G*.

8. A *prism*, which has three flat sides, and when viewed endwise, appears like an equilateral triangle, as *H*.

Glasses ground into any of the shapes *B, C, D, E, F*, are generally called *lenses*.

A right line *LIK*, going perpendicularly through the middle of a lens, is called *the axis of the lens*.

A ray of light *Gb*, falling perpendicularly on a plane glass, *EF*, will pass through the glass in the same direction *bi*, and go out of it into the air in the same right course *iH*. Fig. 6.

A ray of light *AB*, falling obliquely on a plane glass, will go out of the glass in the same direction, but not in the same right line; for in touching the glass, it will be refracted in the line *BC*, and in leaving the glass, it will be refracted in the line *CD*.

5 A ray

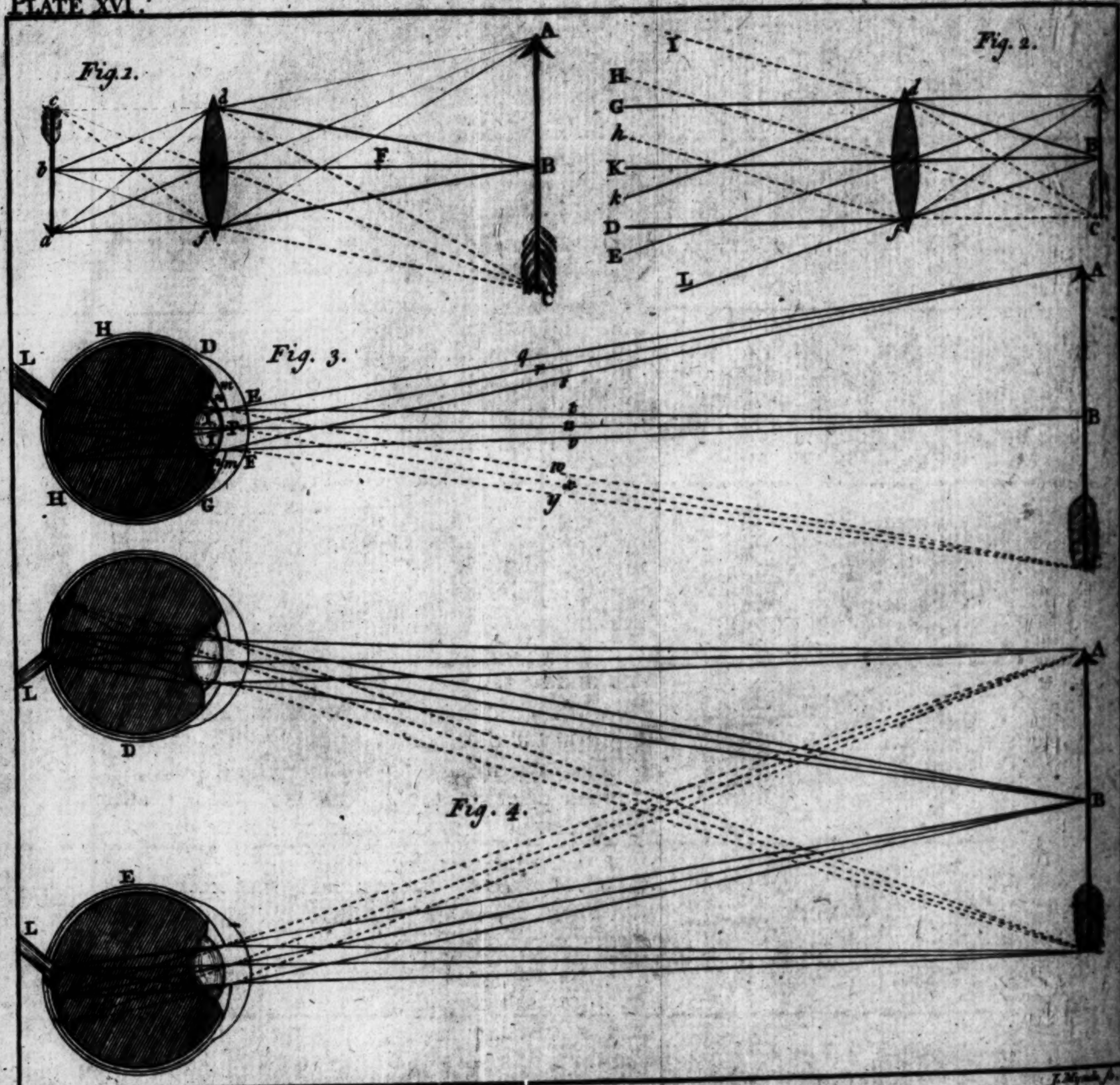
Fig. 7. A ray of light *CD*, falling obliquely o
middle of a convex glaſs, will go forward i
ſame direction *DE*, as if it had fallen wi
ſame degree of obliquity on a plane glaſs,
will go out of the glaſs in the ſame dire
with which it entered: for it will be eq
refracted at the points *D* and *E*, as if it had p
through a plane ſurface. But the rays *C*
CI will be ſo refracted, as to meet again a
point *F*. Therefore, all the rays which
from the point *C*, ſo as to go through the g
will meet again at *F*; and if they go fa
onward, as to *L*, they croſs at *F*, and go
ward on the oppoſite ſides of the midd
CDEF, to what they were in approaching
the directions *HF* and *KF*.

Fig. 8. The properties of different lenſes. When parallel rays, as *ABC*, fall dir
upon a plano-convex glaſs *DE*, and paſs th
it, they will be ſo refracted, as to unite
point *f* behind it; and this point is called
principal focus; the diſtance of which, from
middle of the glaſs, is called the *focal d*
which is equal to twice the radius of the ſp
of the glaſs's convexity. And,

Fig. 9. When parallel rays, as *ABC*, fall di
upon a glaſs *DE*, which is equally conve
both ſides, and paſs through it; they will b
refracted, as to meet in a point or principal f
f, whoſe diſtance is equal to the radius or
diameter of the ſphere of the glaſs's conv
But if a glaſs be more convex on one ſide
on the other, the rule for finding the
diſtance is this; as the ſum of the ſemidia
of both convexities is to the ſemidiame
either, ſo is double the ſemidiameter of
other to the diſtance of the focus. Or,

9

PLATE XVI.



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J. Mynde sc.

the double product of the radii by their ſum, and the quotient will be the diſtance ſought.

Since all thoſe rays of the ſun which paſs through a convex glaſs are collected together in its focus, the force of all their heat is collected into that part; and is in proportion to the common heat of the ſun, as the area of the glaſs is to the area of the focus. Hence we ſee the reaſon why a convex glaſs cauſes the ſun's rays to burn after paſſing through it.

All theſe rays croſs the middle ray in the focus *f*, and then diverge from it, to the contrary ſides, in the ſame manner *FfG*, as they converged in the ſpace *DfE* in coming to it.

If another glaſs *FG*, of the ſame convexity as *DE*, be placed in the rays at the ſame diſtance from the focus, it will refract them ſo, as that after going out of it, they will be all parallel, as *a b c*; and go on in the ſame manner as they came to the firſt glaſs *DE*, through the ſpace *ABC*; but on the contrary ſides of the middle ray *Bfb*: for the ray *ADf* will go on from *f* in the direction *fGa*, and the ray *CEf* in the direction *fFc*; and ſo of the reſt.

The rays diverge from any radiant point, as from a principal focus: therefore, if a candle be placed at *f*, in the focus of the convex glaſs *FG*, the diverging rays in the ſpace *FfG* will be ſo refracted by the glaſs, as, that after going out of it, they will become parallel, as ſhewn in the ſpace *c b a*.

If the candle be placed nearer the glaſs than its focal diſtance, the rays will diverge after paſſing through the glaſs, more or leſs, as the candle is more or leſs diſtant from the focus.

If the candle be placed farther from the glaſs than its focal diſtance, the rays will converge after

after passing through the glass, and meet in a point which will be more or less distant from the glass, as the candle is nearer to, or farther from its focus; and where the rays meet, they will form an inverted image of the flame of the candle; which may be seen on a paper placed in the meeting of the rays.

Plate XVI. Fig. 1. Hence, if any object *A B C* be placed beyond the focus *F* of the convex glass *d e f*, some of the rays which flow from every point of the object, on the side next the glass, will fall upon it, and after passing through it, they will be converged into as many points on the opposite side of the glass, where the image of every point will be formed: and consequently, the image of the whole object, which will be inverted. Thus, the rays *A d*, *A e*, *A f*, flowing from the point *A*, will converge in the space *d a f*, and by meeting at *a*, will there form the image of the point *A*. The rays *B d*, *B e*, *B f*, flowing from the point *B*, will be united at *b* by the refraction of the glass, and will there form the image of the point *B*. And the rays *C d*, *C e*, *C f*, flowing from the point *C*, will be united at *c*, where they will form the image of the point *C*. And so of all the other intermediate points between *A* and *C*. The rays which flow from every particular point of the object, and are united again by the glass, are called *pencils* of *rays*.

If the object *A B C* be brought nearer to the glass, the picture *a b c* will be removed to a greater distance. For then, more rays flowing from every single point, will fall more diverging upon the glass; and therefore cannot be so soon collected into the corresponding points behind it. Consequently, if the distance of the object

AB

ABC be equal to the distance *eB* of the focus of the glass, the rays of each pencil will be so refracted by passing through the glass, that they will go out of it parallel to each other; as *dI*, *eH*, *fb*, from the point *C*; *dG*, *eK*, *fD*, from the point *B*; and *dK*, *eE*, *fL*, from the point *A*: and therefore, there will be no picture formed behind the glass. PlateXVI. Fig. 2.

If the focal distance of the glass, and the distance of the object from the glass, be known, the distance of the picture from the glass may be found by this rule, viz. multiply the distance of the focus by the distance of the object, and divide the product by their difference; the quotient will be the distance of the picture.

The picture will be as much bigger or less than the object, as its distance from the glass is greater or less than the distance of the object. For, as *Be* is to *eb*, so is *AC* to *ca*. So that if *ABC* be the object, *cba* will be the picture; or, if *cba* be the object, *ABC* will be the picture. Fig. 1.

Having described how the rays of light, flowing from objects and passing through convex glasses, are collected into points, and form the images of the objects; it will be easy to understand how the rays are affected by passing through the humours of the eye, and are thereby collected into innumerable points on the bottom of the eye, and thereon form the images of the objects which they flow from. For, the different humours of the eye, and particularly the chrystalline humour, are to be considered as a convex glass; and the rays in passing through them to be affected in the same manner as in passing through a convex glass. The manner of vision.

P The

PlateXVI. Fig. 3.

The eye described.

The eye is nearly globular. It consists of three coats and three humours. The part *DHHG* of the outer coat, is called the *sclerotica*, the rest *DEFG* the *cornea*. Next within this coat is that called the *choroides*, which serves as it were for a lining to the other, and joins with the *iris* *mn*, *mn*. The *iris* is composed of two sets of muscular fibres; the one of a circular form, which contracts the hole in the middle called the *pupil*, when the light would otherwise be too strong for the eye; and the other of radial fibres, tending every where from the circumference of the iris towards the middle of the pupil; which fibres, by their contraction, dilate and enlarge the pupil when the light is weak, in order to let in the more of its rays. The third coat is only a fine expansion of the optic nerve *L*, which spreads like net-work all over the inside of the choroides, and is therefore called the *retina*; upon which are painted (as it were) the images of all visible objects, by the rays of light which either flow or are reflected from them.

Under the *cornea* is a fine transparent fluid like water, which is therefore called the *aqueous humour*. It gives a protuberant figure to the cornea, fills the two cavities *mm* and *nn*, which communicate by the pupil *P*, and has the same limpidity, specific gravity, and refractive power as water. At the back of this lies the *chrystalline humour* *II*, which is shaped like a double convex glass; and is a little more convex on the back than the fore part. It converges the rays, which pass through it from every visible object to its focus at the bottom of the eye. This humour is transparent like chrystal, is much of the consistence of hard jelly, and exceeds the specific

pecific gravity of water in the proportion of 1 to 10. It is inclosed in a fine transparent membrane, from which proceed radial fibres o, called the *ligamentum ciliare*, all around its edge; and join to the circumference of the iris. These fibres have a power of contracting and dilating occasionally, by which means they alter the shape or convexity of the chrystalline humour, and also shift it a little backward or forward in the eye, so as to adapt its focal distance at the bottom of the eye to the different distances of objects; without which provision, we could only see those objects distinctly, that were all at one distance from the eye.

At the back of the chrystalline, lies the *vitreous humour K K*, which is transparent like glass, and is largest of all in quantity, filling the whole orb of the eye, and giving it a globular shape. It is much of a consistence with the white of an egg, and very little exceeds the specific gravity and refractive power of water.

As every point of an object *A B C* sends out rays in all directions, some rays, from every point on the side next the eye, will fall upon the cornea between *E* and *F*; and by passing on through the humours and pupil of the eye, they will be converged to as many points on the retina or bottom of the eye, and will thereon form a distinct inverted picture *c b a* of the object. Thus, the pencil of rays *q r s* that flows from the point *A* of the object, will be converged to the point *a* on the retina; those from the point *B* will be converged to the point *b*; those from the point *C* will be converged to the point *c*; and so of all the intermediate points: by which means the whole image *a b c* is formed, and the object made visible; although it must

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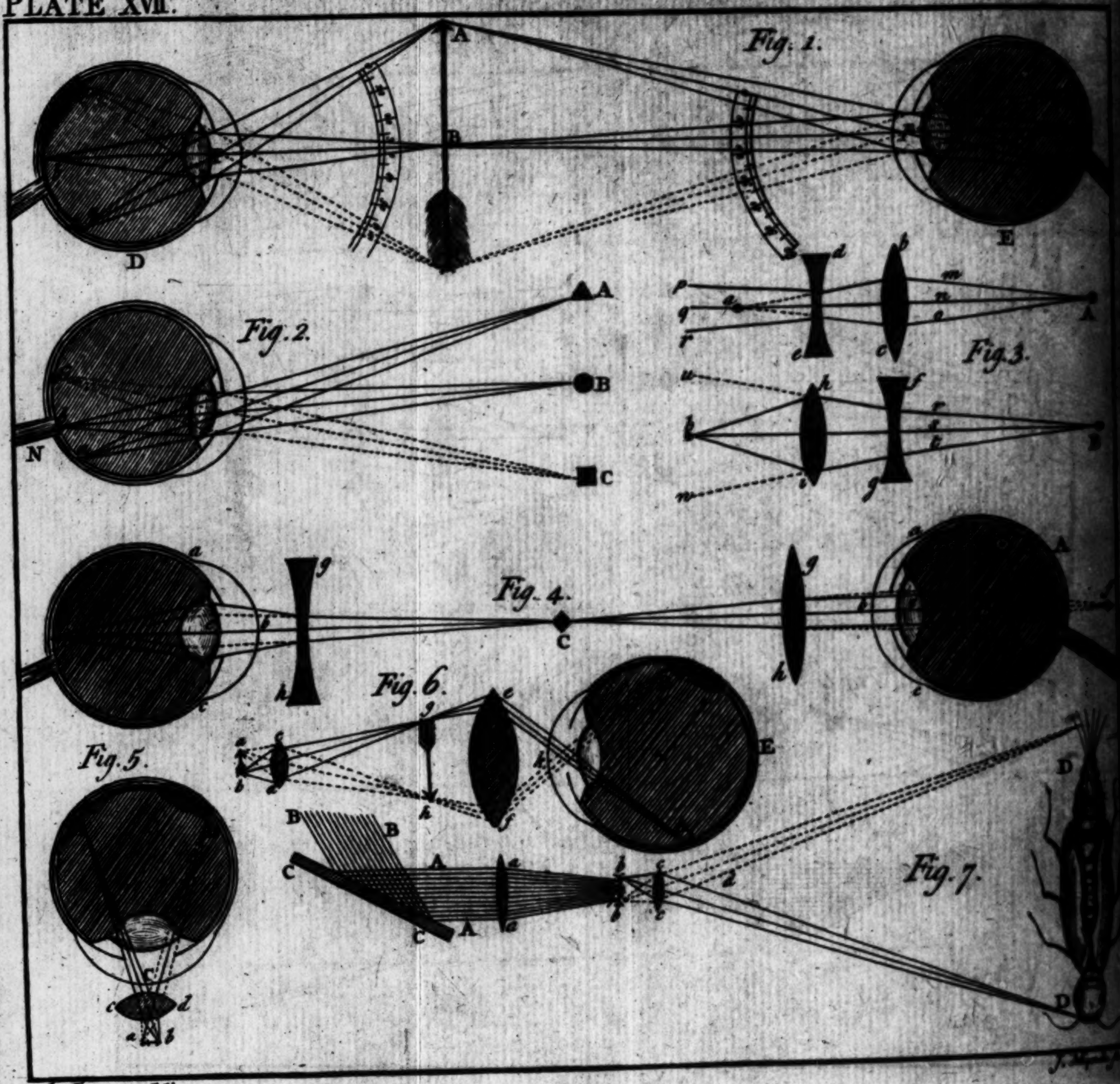
be owned, that the method by which this sensation is carried from the eye by the optic nerve to the common sensory in the brain, and there discerned, is above the reach of our comprehension.

But that vision is effected in this manner may be demonstrated experimentally. Take a bullock's eye whilst it is fresh, and having cut off the three coats from the back part, quite to the vitreous humour, put a piece of white paper over that part, and hold the eye towards any bright object, and you will see an inverted picture of the object upon the paper.

Since the image is inverted, many have wondered why the object appears upright. But we are to consider, 1. that *inverted* is only a relative term; and 2. that there is a very great difference between the real object and the means or image by which we perceive it. When all the parts of a distant prospect are painted upon the retina, they are all right with respect to one another, as well as the parts of the prospect itself; and we can only judge of an object's being inverted, when it is turned reverse to its natural position, with respect to other objects which we see and compare it with.—If we lay hold of an upright stick in the dark, we can tell which is the upper or lower part of it, by moving our hand downward or upward; and know very well that we cannot feel the upper end by moving our hand downward. Just so we find by experience, that upon directing our eyes towards a tall object, we cannot see its top by turning our eyes downward, nor its foot by turning our eyes upward; but must trace the object the same way by the eye to see it from head to foot, as we do by the hand to feel it;

PLATE XVII.



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and as the judgment is informed by the motion of the hand in one case, so it is also by the motion of the eye in the other.

In Fig. 4. is exhibited the manner of seeing the same object *ABC*, by both the eyes *D* and *E* at once. Fig. 4.

When any part of the image *cba* falls upon the optic nerve *L*, the corresponding part of the object becomes invisible. On which account nature has wisely placed the optic nerve of each eye, not in the middle of the bottom of the eye, but towards the side next the nose; so that whatever part of the image falls upon the optic nerve of one eye, may not fall upon the optic nerve of the other. Thus the point *a* of the image *cba* falls upon the optic nerve of the eye *D*, but not of the eye *E*; and the point *c* falls upon the optic nerve of the eye *E*, but not of the eye *D*: and therefore, to both eyes taken together, the whole object *ABC* is visible.

The nearer that any object is to the eye, the larger is the angle under which it is seen, and the magnitude under which it appears. Thus to the eye *D*, the object *ABC* is seen under the angle *APC*; and its image *cba* is very large upon the retina: but to the eye *E*, at a double distance, the same object is seen under the angle *ApC*, which is equal only to half the angle *APC*, as is evident by the figure. The image *cba* is likewise twice as large in the eye *D*, as the other image *cba* is in the eye *E*. In both these representations, a part of the image falls on the optic nerve, and the object in the corresponding part is invisible. Plate XVII. Fig. 1.

As the sense of seeing is allowed to be occasioned by the impulse of the rays from the visible object upon the retina of the eye, and forming the

the image of the object thereon, and that the retina is only the expansion of the optic nerve all over the choroides; it should seem surprising, that the part of the image which falls on the optic nerve should render the like part of the object invisible; especially as that nerve is allowed to be the instrument by which the impulse and image are conveyed to the common sensory in the brain. But this difficulty vanishes, when we consider that there is an artery within the trunk of the optic nerve, which entirely obscures the image in that part, and conveys no sensation to the brain.

That the part of the image which falls upon the middle of the optic nerve is lost, and consequently the corresponding part of the object is rendered invisible, is plain by experiment. For, Fig. 2. if a person fixes three patches, *A*, *B*, *C*, upon a white wall, at the height of the eye, and the distance of about a foot from each other, and places himself before them shutting the right eye, and directing the left towards the patch *C*, he will see the patches *A* and *C*, but the middle patch *B* will disappear. Or, if he shuts his left eye, and directs the right towards *A*, he will see both *A* and *C*, but *B* will disappear; and if he directs his eye towards *B*, he will see both *B* and *A*, but not *C*. For whatever patch is directly opposite to the optic nerve *N*, vanishes. This requires a little practice, after which he will find it easy to direct his eye, so as to lose the sight of whichever patch he pleases.

We are not commonly sensible of this disappearance, because the motions of the eye are so quick and instantaneous, that we no sooner lose the sight of any part of an object, than we recover it again; much the same as in the twinkling of our eyes, for at each twinkling we are

are blinded; but it is so soon over, that we are scarce ever sensible of it.

Some eyes require the assistance of convex glasses to make them see objects distinctly, and others of concave. If either the cornea *a b c* or chrystalline humour *e*, or both of them, be too flat, as in the eye *A*, their focus will not be on the retina, as at *d*, where it ought to be, in order to render vision distinct; but beyond the eye, as at *f*. And therefore, those rays which flow from the object *C*, and pass through the humours of the eye, are not converged enough to unite at *d*; and therefore the observer can have but a very indistinct view of the object. This is remedied by placing a convex glass *g h* before the eye, which makes the rays converge sooner, and imprints the image duly on the retina at *d*. Fig. 4. Why some eyes require spectacles.

If either the cornea, or chrystalline humour, or both of them, be too convex, as in the eye *f*, the rays that enter it from the object *C*, will be converged to a focus in the vitreous humour, as at *f*; and by diverging from thence to the retina, will form a very confused image thereon: and so, of course, the observer will have as confused a view of the object, as if his eye had been too flat. This inconvenience is remedied by placing a concave glass *g h* before the eye; which glass, by causing the rays to diverge between it and the eye, lengthens the focal distance so, that if the glass be properly chosen, the rays will unite at the retina, and form a distinct picture of the object upon it.

Such eyes as have their humours of a due convexity, cannot see any object distinctly at a less distance than six inches; and there are numberless objects too small to be seen at that

distance, because they cannot appear under any sensible angle. The method of viewing such minute objects is by a *microscope*, of which there are three sorts, viz. the *single*, the *double*, and the *solar*.

Fig. 5. The *single microscope*.

The *single microscope* is only a small convex glass, as *c d*, having the object *a b* placed in its focus, and the eye at the same distance on the other side; so that the rays of each pencil, flowing from every point of the object on the side next the glass, may go on parallel to the eye after passing through the glass; and then, by entering the eye at *C*, they will be converged to as many different points on the retina, and form a large inverted picture *A B* upon it, as in the figure.

To find how much this glass magnifies, divide the least distance (which is about six inches) at which an object can be seen distinctly with the bare eye,* by the focal distance of the glass; and the quotient will shew how much the glass magnifies the diameter of the object.

Fig. 6. The *double microscope*.

The *double* or *compound microscope*, consists of an object-glass *c d*, and an eye-glass *e f*. The small object *a b* is placed at a little greater distance from the glass *c d* than its principal focus, so that the pencils of rays flowing from the different points of the object, and passing through the glass, may be made to converge and unite in as many points between *g* and *h*, where the image of the object will be formed; which image is viewed by the eye through the eye-glass *e f*. For the eye-glass being so placed, that the image *g h* may be in its focus, and the eye much about the same distance on the other side, the rays of each pencil will be parallel, after going out of the eye-glass, as at *e* and *f*, till

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till they come to the eye at *k*, where they will begin to converge by the refractive power of the humours; and after having crossed each other in the pupil, and passed through the chrystalline and vitreous humours, they will be collected into points on the retina, and form the large inverted image *A B* thereon.

The magnifying power of this microscope is as follows. Suppose the image *g b* to be six times the distance of the object *a b* from the object-glass *c d*; then will the image be six times the length of the object: but since the image could not be seen distinctly by the bare eye at a less distance than six inches, if it be viewed by an eye-glass *e f*, of one inch focus, it will thereby be brought six times nearer the eye; and consequently viewed under an angle six times as large as before; so that it will be again magnified six times; that is, six times by the object-glass, and six times by the eye-glass, which multiplied into one another, makes 36 times; and so much is the object magnified in diameter more than what it appears to the bare eye; and consequently 36 times 36, or 1296 times in surface.

But, because the extent or field of view is very small in this miscroscope, there are generally two eye-glasses placed sometimes close together, and sometimes an inch asunder; by which means, although the object appears less magnified, yet the visible area is much enlarged by the interposition of a second eye-glass; and consequently a much pleasanter view is obtained.

Fig. 7. The *solar microscope.*

The *solar microscope*, invented by Dr. *Lieberkhun*, is constructed in the following manner. Having procured a very dark room, let a round hole be made in the window-shutter, about three inches

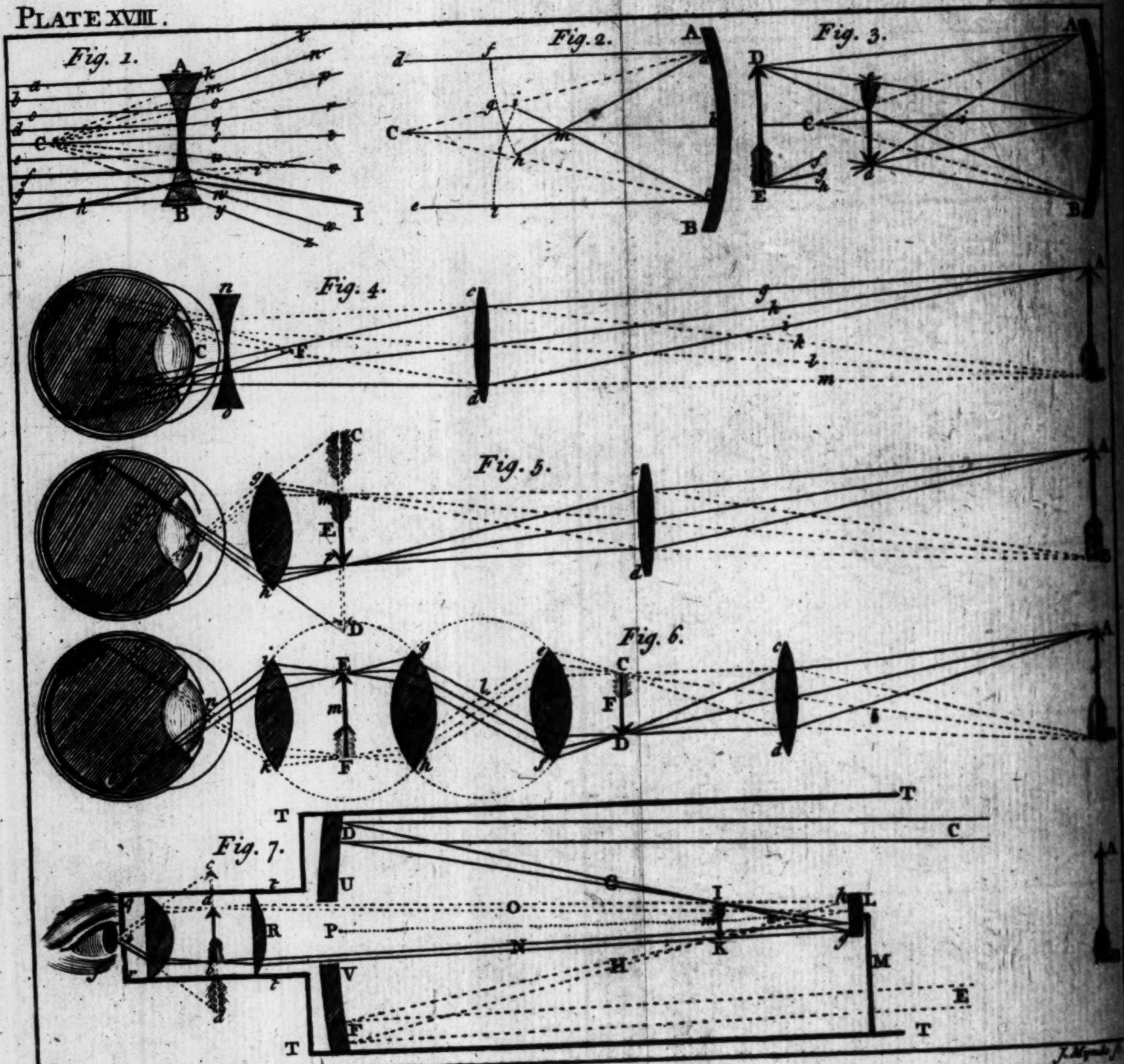
inches diameter, through which the sun may cast a cylinder of rays $A A$ into the room. In this hole, place the end of a tube, containing two convex glasses and an object. viz. 1. A convex glass $a a$, of about two inches diameter, and three inches focal distance, is to be placed in that end of the tube which is put into the hole. 2. The object $b b$, being put between two glasses (which must be concave to hold it at liberty) is placed about two inches and a half from the glass $a a$. 3. A little more than a quarter of an inch from the object is placed the small convex glass $c c$, whose focal distance is a quarter of an inch.

The tube may be so placed, when the sun is low, that his rays $A A$ may enter directly into it: but when he is high, his rays $B B$ must be reflected into the tube by the plane mirrour or looking-glass $C C$.

Things being thus prepared, the rays that enter the tube will be conveyed by the glass $a a$ towards the object $b b$, by which means it will be strongly illuminated; and the rays d which flow from it, through the convex glass $c c$, will make a large inverted picture of the object at $D D$, which, being received on a white paper, will represent the object magnified in length, in proportion of the distance of the picture from the glass $c c$, to the distance of the object from the same glass. Thus, suppose the distance of the object from the glass to be $\frac{3}{10}$ parts of an inch, and the distance of the distinct picture to be 12 feet or 144 inches, in which there are 1440 tenths of an inch; and this number divided by 3 tenths, gives 480; which is the number of times the picture is longer or broader than the object; and the length multiplied by the breadth, shews how much the whole surface is magnified.

Before

PLATE XVIII.



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Before we enter upon the description of telescopes, it will be proper to shew how the rays of light are affected by passing through concave glasses, and also by falling upon concave mirrours. *Telescopes.*

When parallel rays, as *a b c d e f g h*, pass directly through a glass *A B*, which is equally concave on both sides, they will diverge after passing through the glass, as if they had come from a radiant point *C*, in the center of the glass's concavity; which point is called the negative or virtual focus of the glass. Thus the ray *a*, after passing through the glass *A B*, will go on in the direction *k l*, as if it had proceeded from the point *C*, and no glass been in the way. The ray *b* will go on in the direction *m n*; the ray *c* in the direction *o p*, &c.—The ray *C*, that falls directly upon the middle of the glass, suffers no refraction in passing through it; but goes on in the same rectilineal direction, as if no glass had been in its way. Plate XVIII. Fig. 1.

If the glass had been concave only on one side, and the other side quite plane, the rays would have diverged, after passing through it, as if they had come from a radiant point at double the distance of *C* from the glass; that is, as if the radiant had been at the distance of a whole diameter of the glass's concavity.

If rays come more converging to such a glass, than parallel rays diverge after passing through it, they will continue to converge after passing through it; but will not meet so soon as if no glass had been in the way; and will incline towards the same side to which they would have diverged, if they had come parallel to the glass. Thus the rays *f* and *h*, going in a converging state towards the edge of the glass at *B*, and con-

converging more in their way to it than the parallel rays diverge after passing through it, they will go on converging after they pass through it, though in a less degree than they did before, and will meet at *I*: but if no glass had been in their way, they would have met at *i*.

Fig. 2. When the parallel rays, as *dfa*, *Cmb*, *elc*, fall upon a concave mirrour *AB* (which is not transparent, but has only the surface *AbB* of a clear polish) they will be reflected back from that mirrour, and meet in a point *m*, at half the distance of the surface of the mirrour from *C*, the center of its concavity: for they will be reflected at as great an angle from a perpendicular to the surface of the mirrour, as they fell upon it, with regard to that perpendicular; but on the other side thereof. Thus, let *C* be the center of concavity of the mirrour *AbB*, and let the parallel rays *dfa*, *Cmb*, and *elc*, fall upon it at the points *a*, *b*, and *c*. Draw the lines *Cia*, *Cmb*, and *Chc*, from the center *C* to these points; and all these lines will be perpendicular to the surface of the mirrour, because they proceed thereto like so many *radii* or spokes from its center. Make the angle *Cab* equal to the angle *daC*, and draw the line *amb*, which will be the direction of the ray *dfa*, after it is reflected from the point *a* of the mirrour: so that the angle of incidence *daC*, is equal to the angle of reflection *Cab*; the rays making equal angles with the perpendicular *Cia* on its opposite sides.

Draw also the perpendicular *Chc* to the point *c*, where the ray *elc* touches the mirrour; and, having made the angle *Cci* equal to the angle *Cce*, draw the line *cmi*, which will be the course

course of the ray *e l c*, after it is reflected from the mirrour.

The ray *C m b* passing through the center of concavity of the mirrour, and falling upon it at *b*, is perpendicular to it; and is therefore reflected back from it in the same line *b m C*.

All these reflected rays meet in the point *m*; and in that point the image of the body which emits the parallel rays *d a*, *C b*, and *e c*, will be formed: which point is distant from the mirrour equal to half the radius *b m C* of its concavity.

The rays which proceed from any celestial object may be esteemed parallel at the earth; and therefore, the images of that object will be formed at *m*, when the reflecting surface of the concave mirrour is turned directly towards the object. Hence, the focus *m* of parallel rays is not in the center of the mirrour's concavity, but half way between the mirrour and that center.

The rays which proceed from any remote terrestrial object, are nearly parallel at the mirrour; not strictly so, but come diverging to it, in separate pencils, or, as it were, bundles of rays, from each point of the side of the object next the mirrour: and therefore they will not be converged to a point, at the distance of half the radius of the mirrour's concavity from its reflecting surface; but into separate points at a little greater distance from the mirrour. And the nearer the object is to the mirrour, the farther these points will be from it; and an inverted image of the object will be formed in them, which will seem to hang pendent in the air; and will be seen by an eye placed beyond it (with regard to the mirrour) in all respects like

like the object, and as distinct as the object itself.

Fig. 3. Let *AcB* be the reflecting surface of a mirrour, whose center of concavity is at *C*; and let the upright object *DE* be placed beyond the center *C*, and send out a conical pencil of diverging rays from its upper extremity *D*, to every point of the concave surface of the mirrour *AcB*. But to avoid confusion, we only draw three rays of that pencil, as *DA*, *Dc*, *DB*.

From the center of concavity *C*, draw the three right lines *CA*, *Cc*, *CB*, touching the mirrour in the same points where the foresaid rays touch it; and all these lines will be perpendicular to the surface of the mirrour. Make the angle *CAd* equal to the angle *DAC*, and draw the right line *Ad* for the course of the reflected ray *DA*: make the angle *Ccd* equal to the angle *DcC*, and draw the right line *cd* for the course of the reflected ray *Dd*: make also the angle *CBd* equal to the angle *DBC*, and draw the right line *Bd* for the course of the reflected ray *DB*. All these reflected rays will meet in the point *d*, where they will form the extremity *d* of the inverted image *ed*, similar to the extremity *D* of the upright object *DE*.

If the pencil of rays *Ef Eg*, *Eb* be also continued to the mirrour, and their angles of reflection from it be made equal to their angles of incidence upon it, as in the former pencil from *D*, they will all meet at the point *e* by reflection, and form the extremity *e* of the image *ed*, similar to the extremity *E* of the object *DE*.

And as each intermediate point of the object, between *D* and *E*, sends out a pencil of rays in like manner to every part of the mirrour, the

rays of each pencil will be reflected back from it, and meet in all the intermediate points between the extremities *e* and *d* of the image; and so the whole image will be formed, not at *i*, half the distance of the mirrour from its center of concavity *C*; but at a greater distance, between *i* and the object *D E*; and the image will be inverted with respect to the object.

This being well understood, the reader will easily see how the image is formed by the large concave mirrour of the reflecting telescope, when he comes to the description of that instrument.

When the object is more remote from the mirrour than its center of concavity *C*, the image will be less than the object, and between the object and mirrour: when the object is nearer than the center of concavity, the image will be more remote and bigger than the object: thus, if *D E* be the object, *e d* will be its image; for, as the object recedes from the mirrour, the image approaches nearer to it; and as the object approaches nearer to the mirrour, the image recedes farther from it; on account of the lesser or greater divergency of the pencils of rays which proceed from the object: for, the less they diverge, the sooner they are converged to points by reflection; and the more they diverge, the farther they must be reflected before they meet.

If the radius of the mirrour's concavity and the distance of the object from it be known, the distance of the image from the mirrour is found by this rule; divide the product of the distance and radius by double the distance made less by the radius, and the quotient is the distance required.

If

If the object be in the center of the mirrour's concavity, the image and object will be coincident, and equal in bulk.

If a man places himſelf directly before a large concave mirrour, but farther from it than its center of concavity, he will ſee an inverted image of himſelf in the air, between him and the mirrour, of a leſs ſize than himſelf. And if he holds out his hand towards the mirrour, the hand of the image will come out towards his hand, and coincide with it, of an equal bulk, when his hand is in the center of concavity; and he will imagine he may ſhake hands with his image. If he reaches his hand farther, the hand of the image will paſs by his hand, and come between his hand and his body: and if he moves his hand towards either ſide, the hand of the image will move towards the other; ſo that whatever way the object moves, the image will move the contrary.

All the while a by-ſtander will ſee nothing of the image, becauſe none of the reflected rays that form it enter his eyes.

If a fire be made in a large room, and a ſmooth mahogany table be placed at a good diſtance near the wall, before a large concave mirrour, ſo placed, that the light of the fire may be reflected from the mirrour to its focus upon the table; if a perſon ſtands by the table, he will ſee nothing upon it but a longiſh beam of light: but if he ſtands at a diſtance towards the fire, not directly between the fire and mirrour, he will ſee an image of the fire upon the table, large and erect. And if another perſon, who knows nothing of this matter beforehand, ſhould chance to come into the room, and ſhould look from the fire towards the table, he

he would be ſtartled at the appearance; for the table would ſeem to be on fire, and by being near the wainſcot, to endanger the whole houſe. In this experiment, there ſhould be no light in the room but what proceeds from the fire; and the mirrour ought to be at leaſt fifteen inches in diameter. Plate XVIII.

If the fire be darkened by a ſcreen, and a large candle be placed at the back of the ſcreen; a perſon ſtanding by the candle will ſee the appearance of a fine large ſtar, or rather planet, upon the table as bright as Venus or Jupiter. And if a ſmall wax taper (whoſe flame is much leſs than the flame of the candle) be placed near the candle, a ſatellite to the planet will appear on the table: and if the taper be moved round the candle, the ſatellite will go round the planet.

For theſe two pleaſing experiments, I am indebted to the reverend Dr. LONG, *Lowndes*'s profeſſor of aſtronomy at Cambridge, who favoured me with the ſight of them, and many more of his curious inventions.

The refracting teleſcope.

In a *refracting teleſcope*, the glaſs which is neareſt the object in viewing it, is called *the object-glaſs*; and that which is neareſt the eye, is called *the eye-glaſs*. The object-glaſs muſt be convex, but the eye-glaſs may be either convex or concave: and generally, in looking through a teleſcope, the eye is in the focus of the eye-glaſs; though that is not very material: for the diſtance of the eye, as to diſtinct viſion, is indifferent, provided the rays of the pencils fall upon it parallel: only, the nearer the eye is to the end of the teleſcope, the larger is the ſcope or area of the field of view.

Let *c d* be a convex-glaſs fixed in a long tube, and have its focus at *E*. Then, a pencil of rays Fig. 4.

g h i, flowing from the upper extremity *A* of the remote object *A B*, will be so refracted by passing through the glass, as to converge and meet in the point *f*; whilst the pencil of rays *k l m*, flowing from the lower extremity *B*, of the same object *A B*, and passing through the glass, will converge and meet in the point *e*: and the images of the points *A* and *B*, will be formed in the points *f* and *e*. And as all the intermediate points of the object, between *A* and *B*, send out pencils of rays in the same manner, a sufficient number of these pencils will pass through the object glass *c d*, and converge to as many intermediate points between *e* and *f*; and so will form the whole inverted image *e E f*, of the distinct object. But because this image is small, a concave glass *n o* is so placed in the end of the tube next the eye, that its virtual focus may be at *F*. And as the rays of the pencils pass converging through the concave glass, but converge less after passing through it than before, they go on further, as to *b* and *a*, before they meet; and the pencils themselves being made to diverge by passing through the concave glass, they enter the eye, and form the large picture *a b* upon the retina, whereon it is magnified under the angle *b F a*.

But this telescope has one inconveniency which renders it unfit for most purposes, which is, that the pencils of rays being made to diverge by passing through the concave glass *n o*, very few of them can enter the pupil of the eye; and therefore the field of view is but very small, as is evident by the figure. For none of the pencils which flow either from the top or bottom of the object *AB* can enter the pupil of the eye at *C*, but are all stopt by falling upon the iris

above

above and below the pupil: and therefore, only the middle part of the object can be seen when the telescope lies directly towards it, by means of those rays which proceed from the middle of the object. So that to see the whole of it, the telescope must be moved upwards and downwards, unless the object be very remote; and then it is never seen distinctly.

This inconvenience is remedied by substituting a convex eye-glass, as *gh*, in place of the concave one; and fixing it so in the tube, that its focus may be coincident with the focus of the object-glass *cd*, as at *E*. For then, the rays of the pencils flowing from the object *AB*, and passing through the object-glass *cd*, will meet in its focus, and form the inverted image *mEp*: and as the image is formed in the focus of the eye-glass *gh*, the rays of each pencil will be parallel, after passing through that glass; but the pencils themselves will cross in its focus, on the other side, as at *e*: and the pupil of the eye being in this focus, the image will be viewed through the glass, under the angle *geh*; and being at *E*, it will appear magnified, so as to fill the whole space *CmepD*. Fig. 5.

But, as this telescope inverts the image with respect to the object, it gives an unpleasant view of terrestrial objects; and is only fit for viewing the heavenly bodies, in which we regard not their position, because their being inverted does not appear, on account of their being round. But whatever way the object seems to move, this telescope must be moved the contrary way, in order to keep sight of it; for, since the object is inverted, its motion will be so too.

The magnifying power of this telescope is, as the focal distance of the object-glass to the fo-

cal diſtance of the eye-glaſs. Therefore, if the former be divided by the latter, the quotient will expreſs the magnifying power.

When we ſpeak of the magnifying of a teleſcope or microſcope, it is only meant with regard to the diameter, not to the area or ſolidity of the object. But as the inſtrument magnifies the vertical diameter, as much as it does the horizontal, it is eaſy to find how much the whole viſible area or ſurface is magnified: for, if the diameters be multiplied into one another, the product will expreſs the magnification of the whole viſible area. Thus, ſuppoſe the focal diſtance of the object-glaſs be ten times as great as the focal diſtance of the eye glaſs; then, the object will be magnified ten times, both in length and breadth: and 10 multiplied by 10, produces 100; which ſhews, that the area of the object will appear 100 times as big when ſeen through ſuch a teleſcope, as it does to the bare eye.

Hence it appears, that if the focal diſtance of the eye-glaſs, were equal to the focal diſtance of the object-glaſs, the magnifying power of the teleſcope would be nothing.

This teleſcope may be made to magnify in any given degree, provided it be of a ſufficient length. For, the greater the focal diſtance of the object-glaſs, the leſs may be the focal diſtance of the eye-glaſs; though not directly in proportion. Thus, an object-glaſs, of 10 feet focal diſtance, will admit of an eye-glaſs whoſe focal diſtance is little more than $2\frac{1}{2}$ inches; which will magnify near 48 times: but an object-glaſs, of 100 feet focus, will require an eye-glaſs ſomewhat more than 6 inches; and will therefore magnify almoſt 200 times.

A teleſcope for viewing terreſtrial objects, ſhould be ſo conſtructed, as to ſhew them in their natural poſture.

posture. And this is done by one object-glass *cd*, and three eye-glasses *ef*, *gh*, *ik*, so placed, that the distance between any two, which are nearest to each other, may be equal to the sum of their focal distances; as in the figure, where the focus of the glasses *cd* and *ef* meet at *F*, those of the glasses *ef* and *gh*, meet at *l*, and of *gh* and *ik*, at *m*; the eye being at *n*, in or near the focus of the eye-glass *ik*, on the other side. Then, it is plain, that these pencils of rays, which flow from the object *AB*, and pass through the object-glass *cd*, will meet and form an inverted image *CFD* in the focus of that glass; and the image being also in the focus of the glass *ef*, the rays of the pencils will become parallel, after passing through that glass, and cross at *l*, in the focus of the glass *ef*; from whence they pass on to the next glass *gh*, and by going through it they are converged to points in its other focus, where they form an erect image *EmF*, of the object *AB*: and as this image is also in the focus of the eye-glass *ik*, and the eye on the opposite side of the same glass; the image is viewed through the eye-glass in this telescope, in the same manner as through the eye-glass in the former one; only in a contrary position, that is, in the same position with the object. Fig. 6.

The three glasses next the eye, have all their focal distances equal: and the magnifying power of this telescope is found the same way as that of the last above; viz. by dividing the focal distance of the object-glass *cd*, by the focal distance of the eye-glass *ik*, or *gh*, or *ef*, since all these three are equal.

When the rays of light are separated by refraction, they become coloured, and if they be united again, they will be a perfect white. But

Why the object appears coloured when seen through a telescope.

those rays which pass through a convex glass, near its edges are more unequally refracted than those which are nearer the middle of the glass. And when the rays of any pencil are unequally refracted by the glass, they do not all meet again in one and the same point, but in separate points; which makes the image indistinct, and coloured, about its edges. The remedy is, to have a plate with a small round hole in its middle, fixed in the tube at *m*, parallel to the glasses. For, the wandering rays about the edges of the glasses will be stopt, by the plate, from coming to the eye; and none admitted but those which come through the middle of the glass, or at least at a good distance from its edges, and pass through the hole in the middle of the plate. But this circumscribes the image, and lessens the field of view, which would be much larger if the plate could be dispensed with.

The *reflecting telescope*.

The great inconvenience attending the management of long telescopes of this kind, has brought them much into disuse ever since the *reflecting telescope* was invented. For one of this sort, six feet in length, magnifies as much as one of the other an hundred. It was invented by Sir *Isaac Newton*, but has received considerable improvements since his time; and is now generally constructed in the following manner, which was first proposed by Dr. *Gregory*.

Fig. 7.

At the bottom of the great tube *TTTT* is placed the large concave mirrour *DUVF*, whose principal focus is at *m*; and in its middle is a round hole *P*, opposite to which is placed the small mirrour *L*, concave toward the great one; and so fixed to a strong wire *M*, that it may be moved farther from the great mirrour, or nearer to it, by means of a long screw on the out-

outside of the tube, keeping its axis still in the same line *Pmn* with that of the great one.— Now, since in viewing a very remote object, we can scarce see a point of it but what is at least as broad as the great mirrour, we may consider the rays of each pencil, which flow from every point of the object, to be parallel to each other, and to cover the whole reflecting surface *DUVF*. But to avoid confusion in the figure, we shall only draw two rays of a pencil flowing from each extremity of the object into the great tube, and trace their progress, through all their reflections and refractions, to the eye *f*, at the end of the small tube *tt*, which is joined to the great one.

Let us then suppose the object *AB* to be at such a distance, that the rays *C* may flow from its lower extremity *B*, and the rays *E* from its upper extremity *A*. Then the rays *C* falling parallel upon the great mirrour at *D*, will be thence reflected converging, in the direction *DG*; and by crossing at *I* in the principal focus of the mirrour, they will form the upper extremity *I* of the inverted image *IK*, similar to the lower extremity *B* of the object *AB*: and passing on to the concave mirrour *L* (whose focus is at *n*) they will fall upon it at *g*, and be thence reflected converging, in the direction *gN*, because *gm* is longer than *gn*; and passing through the hole *P* in the large mirrour, they would meet somewhere about *r*, and form the lower extremity *d* of the erect image *ad*, similar to the lower extremity *B* of the object *AB*. But by passing through the plano-convex glass *R* in their way, they form that extremity of the image at *b*. In like manner, the rays *E*, which come from the top of the object *AB*, and fall parallel upon the great mirrour at *F*, are thence reflected converg-

ing to its focus, where they form the lower extremity *K* of the inverted image *IK*, similar to the upper extremity *A* of the object *AB*; and thence passing on to the small mirrour *L*, and falling upon it at *b*, they are thence reflected in the converging state *bO*; and going on through the hole *P* of the great mirrour, they will meet somewhere about *q*, and form there the upper extremity *a* of the erect image *a d*, similar to the upper extremity *A* of the object *AB*: but by passing through the convex glass *R* in their way, they meet and cross sooner, as at *a*, where that point of the erect image is formed.—The like being understood of all those rays which flow from the intermediate points of the object, between *A* and *B*, and enter the tube *TT*; all the intermediate points of the image between *a* and *b* will be formed: and the rays passing on from the image through the eye-glass *S*, and through a small hole *e* in the end of the lesser tube *tt*, they enter the eye *f*, which sees the image *a d* (by means of the eye-glass) under the large angle *c e d*, and magnified in length, under that angle from *c* to *d*.

In the best reflecting telescopes, the focus of the small mirrour is never coincident with the focus *m* of the great one, where the first image *IK* is formed, but a little beyond it (with respect to the eye) as at *n*: the consequence of which is, that the rays of the pencils will not be parallel after reflection from the small mirrour, but converge so as to meet in points about *q*, *e*, *r*; where they will form a larger upright image than *a d*, if the glass *R* was not in their way: and this image might be viewed by means of a single eye-glass properly placed between the image and the eye: but then the field of view would be

less,

leſs, and conſequently not ſo pleaſant; for which reaſon, the glaſs *R* is ſtill retained, to enlarge the ſcope or area of the field.

To find the magnifying power of this teleſcope, multiply the focal diſtance of the great mirrour by the diſtance of the ſmall mirrour from the image next the eye, and multiply the focal diſtance of the ſmall mirrour by the focal diſtance of the eye-glaſs: then, divide the product of the former multiplication by the product of the latter, and the quotient will expreſs the magnifying power.

I ſhall here ſet down the dimenſions of one of Mr. *Short*'s reflecting teleſcopes, as deſcribed in Dr. *Smith*'s Optics.

The focal diſtance of the great mirrour 9.6 inches, its breadth 2.3; the focal diſtance of the ſmall mirrour 1.5, its breadth 0.6: the breadth of the hole in the great mirrour 0.5; the diſtance between the ſmall mirrour and the next eye-glaſs 14.2; the diſtance between the two eye-glaſſes 2.4; the focal diſtance of the eye-glaſs next the metals 3.8; and the focal diſtance of the eye-glaſs next the eye 1.1.

One great advantage of the reflecting teleſcope is, that it will admit of an eye-glaſs of a much ſhorter focal diſtance than a refracting teleſcope will; and, conſequently, it will magnify ſo much the more: for the rays are not coloured by reflection from a concave mirrour, if it be ground to a true figure, as they are by paſſing through a convex-glaſs, let it be ground ever ſo true.

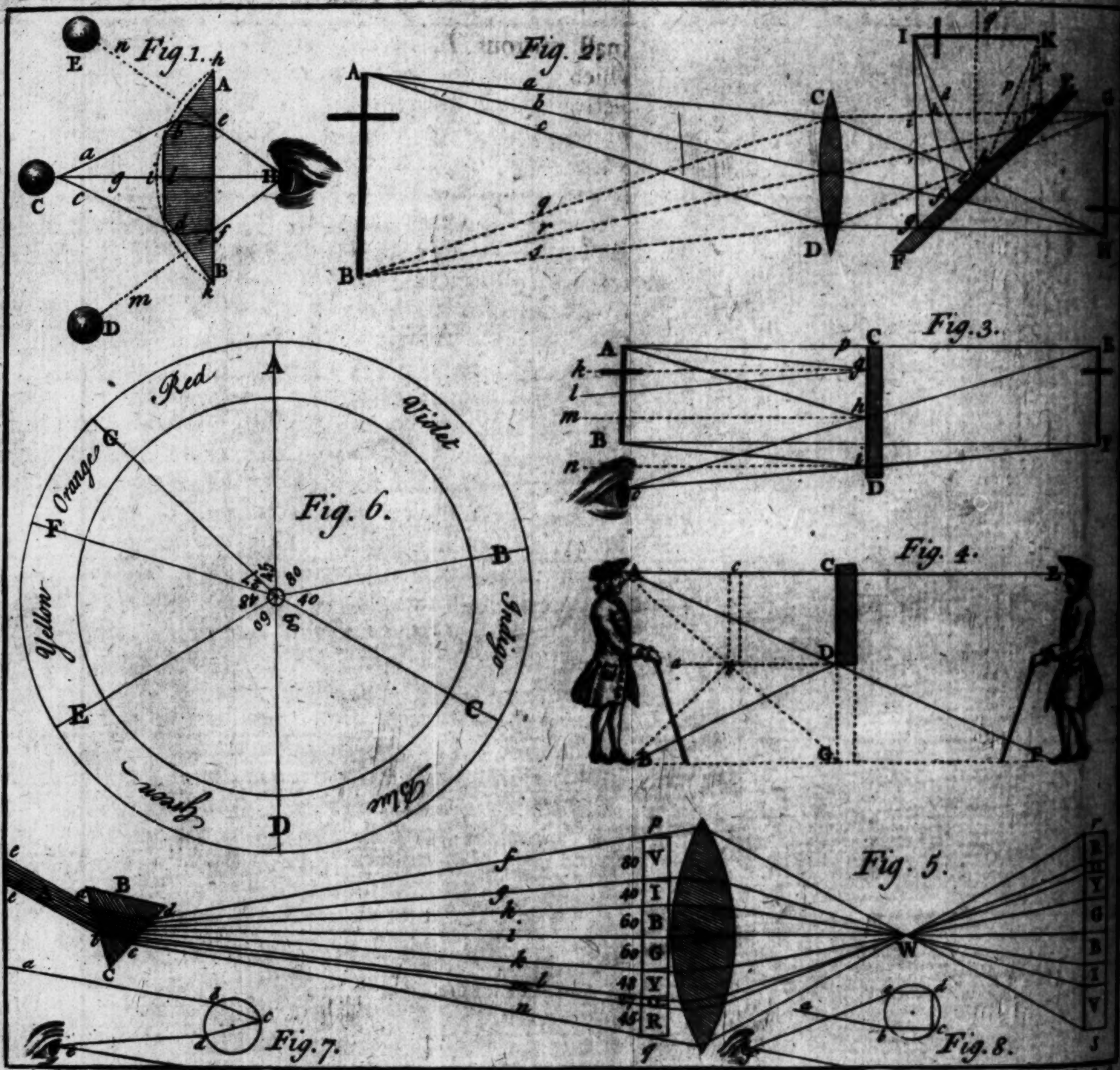
The adjuſting ſcrew on the outſide of the great tube fits this teleſcope to all ſorts of eyes, by bringing the ſmall mirrour either nearer to the eye, or removing it farther: by which

means, the rays are made to diverge a little for short-sighted eyes, or to converge for those of a long sight.

The nearer an object is to the telescope, the more its pencils of rays will diverge before they fall upon the great mirrour, and therefore they will be the longer of meeting in points after reflection; so that the first image *IK* will be formed at a greater distance from the large mirrour, when the object is near the telescope, than when it is very remote. But as this image must be formed farther from the small mirrour than its principal focus *n*, this mirrour must be always set at a greater distance from the large one, in viewing near objects, than in viewing remote ones. And this is done by turning the screw on the outside of the tube, until the small mirrour be so adjusted, that the object (or rather its image) appears perfect.

In looking through any telescope towards an object, we never see the object itself, but only that image of it which is formed next the eye in the telescope. For, if a man holds his finger or a stick between his bare eye and an object, it will hide part (if not the whole) of the object from his view. But if he ties a stick across the mouth of a telescope, before the object-glass, it will hide no part of the imaginary object he saw through the telescope before, unless it covers the whole mouth of the tube: for, all the effect will be, to make the object appear dimmer, because it intercepts part of the rays. Whereas, if he puts only a piece of wire across the inside of the tube, between the eye-glass and his eye, it will hide part of the object which he thinks he sees: which proves that he sees not the real object, but its image. This is also confirmed by means of the

PLATE XIX.



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small mirrour *L*, in the reflecting telescope, which is made of opake metal, and stands directly between the eye and the object towards which the telescope is turned; and will hide the whole object from the eye at *e*, if the two glasses *R* and *S* are taken out of the tube.

Plate XIX. Fig. 1.

The multiplying-glass.

The multiplying glass is made by grinding down the round side *b i k* of a convex glass *A B*, into several flat surfaces, as *h b*, *b l d*, *d k*. An object *C* will not appear magnified, when seen through this glass, by the eye at *H*; but it will appear multiplied into as many different objects as the glass contains plane surfaces. For, since rays will flow from the object *C* to all parts of the glass, and each plane surface will refract these rays to the eye, the same object will appear to the eye, in the direction of the rays which enter it through each surface. Thus, a ray *g i H*, falling perpendicularly on the middle surface, will go through the glass to the eye without suffering any refraction; and will therefore shew the object in its true place at *C*: whilst a ray *a b* flowing from the same object, and falling obliquely on the plane surface *h b*, will be refracted in the direction *b e*, by passing through the glass; and upon leaving it, will go on to the eye in the direction *e H*; which will cause the same object *C* to appear also at *E*, in the direction of the ray *He*, produced in the right line *H e n*. And the ray *c d*, flowing from the object *C*, and falling obliquely on the plane surface *d k*, will be refracted (by passing through the glass and leaving it at *f*) to the eye at *H*; which will cause the same object to appear at *D*, in the direction *H f m*.— If the glass be turned round the line *g l H*, as an axis, the object *C* will keep its place, because the surface *b l d* is not removed; but all the other

other objects will seem to go round *C*, because the oblique planes, on which the rays *a b*, *c d* fall, will go round by the turning of the glass.

Fig. 2. The *camera obscura*.

The *camera obscura* is made by a convex glass *C D*, placed in a hole of a window-shutter. Then, if the room be darkened so, as no light can enter but what comes through the glass, the pictures of all the objects (as fields, trees, buildings, men, cattle, &c.) on the outside, will be shewn in an inverted order, on a white paper placed at *G H* in the focus of the glass: and will afford a most beautiful and perfect piece of perspective or landscape of whatever is before the glass; especially if the sun shines upon the objects.

If the convex glass *C D* be placed in a tube in the side of a square box, within which is the plane mirrour *E F*, reclining backwards in an angle of 45 degrees from the perpendicular *k q*, the pencils of rays flowing from the outward objects, and passing through the convex glass to the plane mirrour, will be reflected upwards from it, and meet in points, as *I* and *K* (at the same distance that they would have met at *H* and *G*, if the mirrour had not been in the way) and will form the aforesaid images on an oiled paper stretched horizontally in the direction *I K*; on which paper, the out-lines of the images may be easily drawn with a black-lead pencil; and then copied on a clean sheet, and coloured by art, as the objects themselves are by nature.— In this machine, it is usual to place a plane glass, unpolished, in the horizontal situation *I K*, which glass receives the images of the outward objects; and their outlines may be traced upon it by a black-lead pencil.

N. B.

N. B. The tube in which the convex glaſs *CD* is fixed, muſt be made to draw out, or puſh in, ſo as to adjuſt the diſtance of that glaſs from the plane mirrour, in proportion to the diſtance of the outward objects; which the operator does, until he ſees their images diſtinctly painted on the horizontal glaſs at *IK*.

The forming a horizontal image, as *IK*, of an upright object *AB*, depends upon the angles of incidence of the rays upon the plane mirrour *EF*, being equal to their angles of reflection from it. For, if a perpendicular be ſuppoſed to be drawn to the ſurface of the plane mirrour at *e*, where the ray *AaCe* falls upon it, that ray will be reflected upwards in an equal angle with the other ſide of the perpendicular, in the line *edI*. Again, if a perpendicular be drawn to the mirrour from the point *f*, where the ray *Abf* falls upon it, that ray will be reflected in an equal angle from the other ſide of the perpendicular, in the line *fbI*. And if a perpendicular be drawn from the point *g*, where the ray *Acg* falls upon the mirrour, that ray will be reflected in an equal angle from the other ſide of the perpendicular, in the line *giI*. So that all the rays of the pencil *abc*, flowing from the upper extremity of the object *AB*, and paſſing through the convex glaſs *CD*, to the plane mirrour *EF*, will be reflected from the mirrour, and meet at *I*, where they will form the extremity *I* of the image *IK*, ſimilar to the extremity *A* of the object *AB*. The like is to be underſtood of the pencil *qrs*, flowing from the lower extremity of the object *AB*, and meeting at *K* (after reflection from the plane mirrour) the rays form the extremity *K* of the image, ſimilar to the extremity *B* of the object: and ſo of all the pencils that flow from the intermediate

termediate points of the object to the mirrour, through the convex glass.

The *opera-glass.* If a convex glass, of a short focal distance, be placed near the plane mirrour, in the end of a short tube, and a convex glass be placed in a hole in the side of the tube, so as the image may be formed between the last-mentioned convex glass, and the plane mirrour; the image being viewed through this glass will appear magnified. —In this manner the *opera-glasses* are constructed; with which a gentleman may look at any lady at a distance in the company, and the lady know nothing of it.

The common *looking-glass.* The image of any object that is placed before a plane mirrour, appears as big to the eye as the object itself; and is erect, distinct, and seemingly as far behind the mirrour, as the object is before it: and that part of the mirrour, which reflects the image of the object to the eye (the eye being supposed equally distant from the glass with the object) is just half as long and half as broad as the object itself. Let *A B* be an object placed before the reflecting surface *g b i* of the plane mirrour *C D*; and let the eye be at *o*. Let *A b* be a ray of light flowing from the top *A* of the object, and falling upon the mirrour at *b*: and *b m* be a perpendicular to the surface of the mirrour at *b*: the ray *A b* will be reflected from the mirrour to the eye at *o*, making an angle *m b o* equal to the angle *A b m*: then will the top of the image *E* appear to the eye in the direction of the reflected ray *o b* produced to *E*, where the right line *A p E*, from the top of the object, cuts the right line *o b E*, at *E*. Let *B i* be a ray of light proceeding from the foot of the object at *B* to the mirrour at *i*; and *n i* a perpendicular to the mirrour from the point *i*, where

Fig. 3.

where the ray *B i* falls upon it: this ray will be reflected in the line *i o*, making an angle *n i o*, equal to the angle *B i n*, with that perpendicular, and entering the eye at *o*: then will the foot *F* of the image appear in the direction of the reflected ray *o i*, produced to *F*, where the right line *B F* cuts the reflected ray produced to *F*. All the other rays that flow from the intermediate points of the object *A B*, and fall upon the mirrour between *b* and *i*, will be reflected to the eye at *o*; and all the intermediate points of the image *E F* will appear to the eye in the direction line of these reflected rays produced. But all the rays that flow from the object, and fall upon the mirrour above *b*, will be reflected back above the eye at *o*; and all the rays that flow from the object, and fall upon the mirrour below *i*, will be reflected back below the eye at *o*: so that none of the rays that fall above *b*, or below *i*, can be reflected to the eye at *o*; and the distance between *b* and *i* is equal to half the length of the object *A B*.

A man will see his image in a plane looking-glass, that is but half his height. Fig. 4.

Hence it appears, that if a man sees his whole image in a plane looking-glass, the part of the glass that reflects his image must be just half as long and half as broad as himself, let him stand at any distance from it whatever; and that his image must appear just as far behind the glass as he is before it. Thus, the man *A B* viewing himself in the plane mirrour *C D*, which is just half as long as himself, sees his whole image as at *E F*, behind the glass, exactly equal to his own size. For, a ray *A C* proceeding from his eye at *A*, and falling perpendicularly upon the surface of the glass at *C*, is reflected back to his eye in the same line *C A*; and the eye of his image will appear at *E*, in the same line produced

duced to *E*, beyond the glaſs. And a ray *B D*, flowing from his foot, and falling obliquely on the glaſs at *D*, will be reflected as obliquely on the other ſide of the perpendicular *a b D*, in the direction *D A*; and the foot of his image will appear at *F*, in the direction of the reflected ray *A D*, produced to *F*, where it is cut by the right line *b G F*, drawn parallel to the right line *ACE*. Juſt the ſame as if the glaſs were taken away, and a real man ſtood at *F*, equal in ſize to the man ſtanding at *B*; for to his eye at *A*, the eye of the other man at *E* would be ſeen in the direction of the line *A C E*; and the foot of the man at *F* would be ſeen by the eye *A*, in the direction of the line *A D F*.

If the glaſs be brought nearer the man *AB*, as ſuppoſe to *c b*, he will ſee his image as at *C D G*: for the reflected ray *C A* (being perpendicular to the glaſs) will ſhew the eye of the image as at *C*; and the incident ray *B b*, being reflected in the line *b A*, will ſhew the foot of his image as at *G*; the angle of reflection *a b A* being always equal to the angle of incidence *B b a*: and ſo of all the intermediate rays from *A* to *B*. Hence, if the man *AB* advances towards the glaſs *C D*, his image will approach towards it; and if he recedes from the glaſs, his image will alſo recede from it.

Having already ſhewn, that the rays of light are refracted when they paſs obliquely through different mediums, we come now to prove that ſome rays are more refrangible than others; and that, as they are differently refracted, they excite in our minds the ideas of different colours. This will account for the colours ſeen about the edges of the images of thoſe objects which are viewed through ſome teleſcopes.

Let

Let the sun shine into a dark room through a small hole, as at *e e*, in a window-shutter; and place a triangular prism *B C* in the beam of rays *A*, in such a manner, that the beam may fall obliquely on one of the sides *a b C* of the prism. The rays will suffer different refractions by passing through the prism, so that instead of going all out of it on the side *d c C*, in one direction, they will go on from it in the different directions represented by the lines *f, g, h, i, k, l, m, n*; and falling upon the opposite side of the room, or on white paper placed as at *p q*, to receive them, they will paint upon it a series of most beautiful lively colours (not to be equalled by art) in this order, viz. those rays which are least refracted by the prism, and will therefore go on between the lines *n* and *m*, will be of a very bright intense red at *n*, degenerating from thence gradually into an orange colour, as they are nearer the line *m*: the next will be of a fine orange colour at *m*, and from thence degenerate into a yellow colour towards *l*: at *l* they will be of a fine yellow, which will incline towards a green, more and more, as they are nearer and nearer *k*: at *k* they will be a pure green, but from thence towards *i* they will incline gradually to a blue: at *i* they will be a perfect blue, inclining to an indigo colour from thence towards *h*: at *h* they will be quite the colour of indigo, which will gradually change towards a violet, the nearer they are to *g*: and at *g* they will be of a fine violet colour, which will incline gradually to a red as they come nearer to *f*, where the coloured image ends.

Fig. 5.

The prism.

The colours of the light.

There is not an equal quantity of rays in each of these colours; for, if the oblong image *p q* be divided into 360 equal parts, the red space

R will take up 45 of these parts; the orange *O*, 27; the yellow *Y*, 48; the green *G*, 60; the blue *B*, 60; the indigo *I*, 40; and the violet *V*, 80: all which spaces are as nearly proportioned in the figure as the small space *q p* would admit of.

If all these colours be blended together again, they will make a pure white; as is proved thus. Take away the paper on which the colours *p q* fell, and place a large convex glass *D* in the rays *f*, *g*, *h*, &c. which will refract them so, as to make them unite and cross each other at *W*: and if a white paper be placed to receive them, they will excite the idea of a strong lively white. But if the paper be placed farther from the glass, as at *r s*, the different colours will appear again upon it, in an inverted order, occasioned by the rays crossing at *W*.

As white is a composition of all colours, so black is a privation of them all, and, therefore, properly no colour.

Fig. 6. Let two concentric circles be drawn on a smooth round board *ABCDEFG*, and the outermost of them divided into 360 equal parts or degrees: then, draw seven right lines, as ⊙ *A*, ⊙ *B*, &c. from the center to the outermost circle; making the lines ⊙ *A* and ⊙ *B* include 80 degrees of that circle; the lines ⊙ *B* and ⊙ *C* 40 degrees; ⊙ *C* and ⊙ *D* 60; ⊙ *D* and ⊙ *E* 60; ⊙ *E* and ⊙ *F* 48; ⊙ *F* and ⊙ *G* 27; ⊙ *G* and ⊙ *A* 45. Then, between these two circles, paint the space *AG* red, inclining to orange near *G*; *GF* orange, inclining to yellow near *F*; *FE* yellow, inclining to green near *E*; *ED* green, inclining to blue near *D*; *DC* blue, inclining to indigo near *C*; *CB* indigo, inclining to violet near *B*; and *BA* violet, inclining to a soft red near *A*. This done, paint all that part of the board black

which

which lies within the inner circle; and putting an axis through the center of the board, let it be turned very ſwiftly round that axis, ſo as the rays proceeding from the above colours, may be all blended and mixt together in coming to the eye; and then, the whole coloured part will appear like a white ring, a little greyiſh; not perfectly white, becauſe no colours prepared by art are perfect.

All the priſmatic colours blended together, make a white.

Any of theſe colours, except red and violet, may be made by mixing together the two contiguous priſmatic colours. Thus, yellow is made by mixing together a due proportion of orange and green; and green may be made by a mixture of yellow and blue.

All bodies appear of that colour, whoſe rays they reflect moſt; as a body appears red when it reflects moſt of the red-making rays, and abſorbs the reſt.

Tranſparent colours become opake if put together.

Any two or more colours that are quite tranſparent by themſelves, become opake when put together. Thus, if water or ſpirits of wine be tinged red, and put in a phial, every object ſeen through it will appear red; becauſe it lets only the red rays paſs through it, and ſtops all the reſt. If water or ſpirits be tinged blue, and put in a phial, all objects ſeen through it will appear blue, becauſe it tranſmits only the blue rays, and ſtops all the reſt. But if theſe two phials are held cloſe together, ſo as both of them may be between the eye and object, the object will no more be ſeen through them than through a plate of metal; for whatever rays are tranſmitted through the fluid in the phial next the object, are ſtopped by that in the phial next the eye. In this experiment, the phials ought not to be round, but ſquare; becauſe nothing but the

light itself can be seen through a round transparent body, at any distance.

As the rays of light suffer different degrees of refraction by passing obliquely through a prism, or through a convex glass, and are thereby separated into all the seven original or primary colours; so they also suffer different degrees of refraction by passing through drops of falling rain; and then, being reflected towards the eye, from the sides of these drops which are farthest from the eye, and again refracted by passing out of these drops into the air, in which refracted directions they come to the eye; they make all the colours to appear in the form of a fine arch in the heavens, which is called the *rain-bow*.

There are always two rain-bows seen together, the interior of which is formed by the rays *a b*, which falling upon the upper part *b*, of the drop *b c d*, are refracted into the line *b c* as they enter the drop, and are reflected from the back of it at *c*, in the line *c d*, and then, by passing out of the drop into air, they are again refracted at *d*; and from thence they pass on to the eye at *e*: so that to form the interior bow, the rays suffer two refractions, as at *b* and *d*; and one reflection, as at *c*.

Fig. 7.

The exterior bow is formed by rays which suffer two reflections, and two refractions; which is the occasion of its being less vivid than the interior, and also of its colours being inverted with respect to those of the interior. For, when a ray *a b* falls upon the lower part of the drop *b c d e*, it is refracted into the direction *b c* by entering the drop; and passing on to the back of the drop at *c*, it is thence reflected in the line *c d*, in which direction it is impossible for it to enter the eye at *f*: but by being again reflected

Fig. 8.

ted from the point *d* of the drop, it goes on in the drop to *e*, where it passes out of the drop into the air, and is there refracted downward to the eye, in the direction *e f*.

LECT. VIII AND IX.

The description and use of the globes, and armillary sphere.

IF a map of the world be accurately delineated on a spherical ball, the surface thereof will represent the surface of the earth: for the highest hills are so inconsiderable with respect to the bulk of the earth, that they take off no more from its roundness, than grains of sand do from the roundness of a common globe; for the diameter of the earth is 8000 miles, in round numbers, and no known hill upon it is three miles in perpendicular height. The *terrestrial globe.*

That the earth is spherical, or round like a globe, appears, 1. from its casting a round shadow upon the moon, whatever side be turned towards her when she is eclipsed. 2. From its having been sailed round by several persons. 3. From our seeing the farther, the higher we stand. 4. From our seeing the masts of a ship, whilst the hull is hid by the convexity of the water. Proof of the earth's being globular.

The attractive power of the earth draws all terrestrial bodies towards its center; as is evident from the descent of bodies in lines perpendicular to the earth's surface, at the places whereon they fall; even when they are thrown off from the earth on opposite sides, and consequently, in opposite directions. So that the earth And that it may be peopled on all sides without any one's being in danger of falling away from it.

earth may be compared to a great magnet rolled in filings of steel, which attracts and keeps them equally fast to its surface on all sides. Hence, as all terrestrial bodies are attracted toward the earth's center, they can be in no danger of falling from any side of the earth, more than from any other.

Up and *down*, what.

The heaven or sky surrounds the whole earth: and when we speak of *up* or *down*, we mean only with regard to ourselves; for no point, either in the heaven, or on the surface of the earth, is *above* or *below*, but only with respect to ourselves. And let us be upon what part of the earth we will, we stand with our feet towards its center, and our heads toward the sky: and so we say, it is *up* toward the sky, and *down* toward the center of the earth.

All objects in the heaven appear equally distant.

To an observer placed any where in the indefinite space, where there is nothing to limit his view, all remote objects appear equally distant from him; and seem to be placed in a vast concave sphere, of which his eye is the center. Every astronomer can demonstrate, that the moon is much nearer to us than the sun is; that some of the planets are sometimes nearer to us, and sometimes farther from us, than the sun; that others of them never come so near us as the sun always is; that the remotest planet in our system, is beyond comparison nearer to us than any of the fixed stars are; and that it is highly probable some stars are, in a manner, infinitely more distant from us than others. And yet all these celestial objects appear equally distant from us. Therefore, if we

The face of the heaven and earth

imagine a large hollow sphere of glass to have as many bright studs fixed to its inside, as there are stars visible in the heaven, and these

studs

ſtuds to be of different magnitudes, and placed at the ſame angular diſtances from each other as the ſtars are; the ſphere will be a true repreſentation of the ſtarry heaven, to an eye ſuppoſed to be in its center, and viewing it all around. And if a ſmall globe, with a map of the earth upon it, be placed on an axis in the center of this ſtarry ſphere, and the ſphere be made to turn round on this axis, it will repreſent the apparent motion of the heavens round the earth. repreſented in a machine.

If a great circle be ſo drawn upon this ſphere, as to divide it into two equal parts, or hemiſpheres, and the plane of the circle be perpendicular to the axis of the ſphere, this circle will repreſent the *equinoctial*, which divides the heaven into two equal parts, called the *northern* and the *ſouthern hemiſpheres*; and every point of that circle will be equally diſtant from the *poles*, or ends of the axis in the ſphere. That pole which is in the middle of the northern hemiſphere, will be called the *north pole of the ſphere*, and that which is in the middle of the ſouthern hemiſphere, the *ſouth pole*.

The *equinoctial*.

The *poles*.

If another great circle be drawn upon the ſphere, in ſuch a manner as to cut the equinoctial at an angle of 23½ degrees in two oppoſite points, it will repreſent the *ecliptic*, or circle of the ſun's apparent annual motion: one half of which is on the north ſide of the equinoctial, and the other half on the ſouth.

The *ecliptic*.

If a large ſtud be made to move eaſtward in this ecliptic, in ſuch a manner as to go quite round it, in the time that the ſphere is turned round weſtward 366 times upon its axis; this ſtud will repreſent the *ſun*, changing his place every day a 365th part of the ecliptic; and

The *ſun*.

going round westward, the same way as the stars do; but with a motion so much slower than the motion of the stars, that they will make 366 revolutions about the axis of the sphere, in the time that the sun makes only 365. During one half of these revolutions, the sun will be on the north side of the equinoctial; during the other half, on the south; and at the end of each half, in the equinoctial.

The *earth*.

If we suppose the terrestrial globe in this machine to be about one inch in diameter, and the diameter of the starry sphere to be about five or six feet, a small insect on the globe would see only a very little portion of its surface; but it would see one half of the starry sphere; the convexity of the globe hiding the other half from its view. If the sphere be turned westward round the globe, and the insect could judge of the appearances which arise from that motion, it would see some stars rising to its view in the eastern side of the sphere, whilst others were setting on the western: but as all the stars are fixed to the sphere, the same stars would always rise in the same points of view on the east side, and set in the same points of view on the west side. With the sun it would be otherwise, because the sun is not fixed to any point of the sphere, but moves slowly along an oblique circle in it. And if the insect should look towards the south, and call that point of the globe, where the equinoctial in the sphere seems to cut it on the left side, the *east point*; and where it cuts the globe on the right side, the *west point*; the little animal would see the sun rise north of the east, and set north of the west, for 182½ revolutions; after which, for as many more, the sun would rise south of the east, and set south of the west.

The apparent motion of of the heavens.

west. And in the whole 365 revolutions, the sun would rise only twice in the east point, and set twice in the west. All these appearances would be the same, if the starry sphere stood still (the sun only moving in the ecliptic) and the earthly globe were turned round the axis of the sphere eastward. For, as the insect would be carried round with the globe, he would be quite insensible of its motion; and the sun and stars would appear to move westward.

We are but very small beings when compared with our earthly globe, and *the globe itself* is but a dimensionless point compared with the magnitude of the starry heavens. Whether the earth be at rest, and the heaven turns round it, or the heaven be at rest, and the earth turns round, the appearance to us will be exactly the same. And because the heaven is so immensely large, in comparison of the earth, we see one half of the heaven as well from the earth's surface, as we could do from its center, if the limits of our view are not intercepted by hills.

Circles of the sphere.

We may imagine as many circles described upon the earth as we please; and we may imagine the plane of any circle described upon the earth to be continued, until it marks a circle in the concave sphere of the heavens.

The horizon.

The *horizon* is either *sensible* or *rational.* The *sensible* horizon is that circle, which a man standing upon a large plane, observes to terminate his view all around, where the heaven and earth seem to meet. The plane of our sensible horizon continued to the heaven, divides it into two hemispheres; one visible to us, the other hid by the convexity of the earth.

The

The plane of the *rational horizon*, is ſuppoſed parallel to the plane of the ſenſible; to paſs through the center of the earth, and to be continued to the heavens. And although the plane of the ſenſible horizon touches the earth in the place of the obſerver, yet *this* plane, and *that* of the rational horizon, will ſeem to coincide in the heaven, becauſe the whole earth is but a point compared to the ſphere of the heaven.

The earth being a ſpherical body, the horizon, or limit of our view, muſt change as we change our place.

Poles. The *poles of the earth*, are thoſe two points on its ſurface in which its axis terminates. The one is called the *north pole*, and the other the *ſouth pole.*

The *poles of the heaven*, are thoſe two points in which the earth's axis produced terminates in the heaven: ſo that the *north pole* of the heaven is directly over the north pole of the earth; and the *ſouth pole* of the heaven is directly over the ſouth pole of the earth.

Equator. The *equator* is a great circle upon the earth, every part of which is equally diſtant from either of the poles. It divides the earth into two equal parts, called the *northern* and *ſouthern hemiſpheres.* If we ſuppoſe the plane of this circle to be extended to the heaven, it will mark the *equinoctial* therein, and will divide the heaven into two equal parts, called the *northern* and *ſouthern* hemiſpheres of the heaven.

Meridian. The *meridian* of any place is a great circle paſſing through that place and the poles of the earth. We may imagine as many ſuch meridians as we pleaſe, becauſe any place that is

every

ever ſo little to the eaſt or weſt of any other place, has a different meridian from that place; for no one circle can paſs through any two ſuch places and the poles of the earth.

The *meridian* of any place is divided by the poles, into two ſemicircles: that which paſſes through the place is called the *geographical*, or *upper meridian*; and that which paſſes through the oppoſite place, is called the *lower meridian*.

Noon and *mid-night.* When the rotation of the earth brings the plane of the geographical meridian to the ſun, it is *noon* or *mid-day* to that place; and when the lower meridian comes to the ſun, it is *mid-night*.

All places lying under the ſame geographical meridian, have their noon at the ſame time, and conſequently all the other hours. All thoſe places are ſaid to have the ſame *longitude*, becauſe no one of them lies either eaſtward or weſtward from any of the reſt.

Hour-circles. If we imagine 24 ſemicircles, one of which is the geographical meridian of a given place, to meet at the poles, and to divide the equator into 24 equal parts; each of theſe meridians will come round to the ſun in 24 hours, by the earth's equable motion round its axis in that time. And, as the equator contains 360 degrees, there will be 15 degrees contained between any two of theſe meridians which are neareſt to one another: for 24 times 15 is 360. And as the earth's motion is eaſtward, the ſun's apparent motion will be weſtward, at the rate of 15 degrees each hour. Therefore,

Longitude. They whoſe geographical meridian is 15 degrees eaſtward from us, have noon, and every other hour, an hour ſooner than we have. They whoſe meridian is fifteen degrees weſtward from us,

us, have noon, and every other hour, an hour later than we have: and so on in proportion, reckoning one hour for every fifteen degrees.

As the earth turns round its axis once in 24 hours, and shews itself all round to the sun in that time; so it goes round the sun once a year, in a great circle called the *ecliptic*, which crosses the equinoctial in two opposite points, making an angle of $23\frac{1}{2}$ degrees with the equinoctial on each side. So that one half of the ecliptic is in the northern hemisphere, and the other in the southern. It contains 360 equal parts, called degrees (as all other circles do, whether great or small) and as the earth goes once round it every year, the sun will appear to do the same, changing his place almost a degree, at a mean rate, every 24 hours. So that whatever place, or degree of the ecliptic, the earth is in at any time, the sun will then appear in the opposite. And as one half of the ecliptic is on the north side of the equinoctial, and the other half on the south; the sun, as seen from the earth, will be half a year on the south side of the equinoctial, and half a year on the north: and twice a year in the equinoctial itself.

Ecliptic.

Signs and *degrees.*

The ecliptic is divided by astronomers into 12 equal parts, called *signs*, each sign into 30 *degrees*, and each degree into 60 *minutes*: but in using the globes, we seldom want the sun's place nearer than half a degree of the truth.

The names and characters of the 12 signs are as follow; beginning at that point of the ecliptic where it crosses the equinoctial to the northward, and reckoning eastward round to the same point again. And the days of the months on which the sun now enters the signs, are set down below them.

Aries,

Aries,	*Taurus,*	*Gemini,*	*Cancer,*
♈	♉	♊	♋
March	April	May	June
20	20	21	21
Leo,	*Virgo,*	*Libra,*	*Scorpio,*
♌	♍	♎	♏
July	August	September	October
23	23	23	23
Sagittarius,	*Capricorn,*	*Aquarius,*	*Pisces,*
♐	♑	♒	♓
November	December	January	February
22	21	20	18

By remembering on what day the ſun enters any particular ſign, we may eaſily find his place any day afterward, whilſt he is in that ſign, by reckoning a degree for each day; which will occaſion no error of conſequence in uſing the globes.

When the ſun is at the beginning of *Aries*, he is in the equinoctial; and from that time he declines northward every day, until he comes to the beginning of *Cancer*, which is 23½ degrees from the equinoctial: from thence he recedes ſouthward every day, for half a year; in the middle of which half, he croſſes the equinoctial at the beginning of *Libra*, and at the end of that half year, he is at his greateſt ſouth declination, in the beginning of *Capricorn*, which is alſo 23½ degrees from the equinoctial. Then, he returns northward from *Capricorn* every day, for half a year; in the middle of which half, he croſſes the equinoctial at the beginning of *Aries*; and at the end of it he arrives at *Cancer*.

The

The sun's motion in the ecliptic is not perfectly equable; for he continues eight days longer in the northern half of the ecliptic, than in the southern: so that the summer half year, in the northern hemisphere, is eight days longer than the winter half year; and the contrary in the southern hemisphere.

Tropics. The *tropics* are lesser circles in the heaven, parallel to the equinoctial; one on each side of it, touching the ecliptic in the points of its greatest declination; so that each tropic is $23\frac{1}{2}$ degrees from the equinoctial, one on the north side of it, and the other on the south. The northern tropic touches the ecliptic at the beginning of *Cancer*, the southern at the beginning of *Capricorn*; for which reason the former is called the *tropic of Cancer*, and the latter the *tropic of Capricorn*.

Polar circles. The *polar circles* in the heaven, are each $23\frac{1}{2}$ degrees from the poles, all around. That which goes round the north pole, is called the *arctic circle*, from ἄρκτος, which signifies a *bear*; there being a collection or groupe of stars near the north pole, which goes by that name. The south polar circle, is called the *antarctic circle*, from its being opposite to the arctic.

The ecliptic, tropics, and polar circles, are drawn upon the terrestrial globe, as well as upon the celestial. But the ecliptic, being a great fixed circle in the heavens, cannot properly be said to belong to the terrestrial globe; and is laid down upon it only for the conveniency of solving some problems. So that, if this circle on the terrestrial globe was properly divided into the months and days of the year, it would not only suit the globe better, but would also make the problems thereon much easier.

In

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In order to form a true idea of the earth's motion round its axis every 24 hours, which is the cauſe of day and night; and of its motion in the ecliptic round the ſun every year, which is the cauſe of the different lengths of days and nights, and of the viciſſitude of ſeaſons; take the following method, which will be both eaſy and pleaſant.

An idea of the ſeaſons.

Let a ſmall terreſtrial globe, of about three inches diameter, be ſuſpended by a long thread of twiſted ſilk, fixt to its north pole: then having placed a lighted candle on a table, to repreſent the ſun, in the center of a hoop of a large caſk, which may repreſent the ecliptic, the hoop making an angle of $23\frac{1}{2}$ degrees with the plane of the table; hang the globe within the hoop near to it; and if the table be level, the equator of the globe will be parallel to the table, and the plane of the hoop will cut the equator at an angle of $23\frac{1}{2}$ degrees; ſo that one half of the equator will be above the hoop, and the other half below it: and the candle will enlighten one half of the globe, as the ſun enlightens one half of the earth, whilſt the other half is in the dark.

Things being thus prepared, twiſt the thread towards the left hand, that it may turn the globe the ſame way by untwiſting; that is, from weſt, by ſouth, to eaſt. As the globe turns round its axis or thread, the different places of its ſurface will go regularly through the light and dark; and have, as it were, an alternate return of day and night in each rotation. As the globe continues to turn round, and to ſhew itſelf all around to the candle, carry it ſlowly round the hoop by the thread, from weſt, by ſouth, to eaſt; which is the way that the earth moves

moves round the sun, once a year, in the ecliptic: and you will see, that whilst the globe continues in the lower part of the hoop, the candle (being then north of the equator) will constantly shine round the north pole; and all the northern places which go through any part of the dark, will go through a less portion of it than they do of the light; and the more so, the farther they are from the equator: consequently, their days are then longer than their nights. When the globe comes to a point in the hoop, mid-way between the highest and lowest points, the candle will be directly over the equator, and will enlighten the globe just from pole to pole; and then every place on the globe will go through equal portions of light and darkness, as it runs round its axis; and consequently, the day and night will be of equal length at all places upon it. As the globe advances thenceforward, towards the highest part of the hoop, the candle will be on the south side of the equator, shining farther and farther round the south pole, as the globe rises higher and higher in the hoop; leaving the north pole as much in darkness, as the south pole is then in the light, and making long days and short nights on the south side of the equator, and the contrary on the north side, whilst the globe continues in the northern or higher side of the hoop: and when it comes to the highest point, the days will be at the longest, and the nights at the shortest, in the southern hemisphere; and the reverse in the northern. As the globe advances and descends in the hoop, the light will gradually recede from the south pole, and approach towards the north pole, which will cause the northern days to lengthen, and the southern days to shorten in

the

the ſame proportion. When the globe comes to the middle point, between the higheſt and loweſt points of the hoop, the candle will be over the quator, enlightening the globe juſt from pole o pole, when every place of the earth (except e poles) will go through equal portions of ight and darkneſs; and conſequently, the day nd night will be then equal, all over the globe.

And thus at a very ſmall expence, one may ave a delightful and demonſtrative view of he cauſe of days and nights, with their gradual creaſe and decreaſe in length, through the hole year together, with the viciſſitudes of ring, ſummer, autumn, and winter, in each nual courſe of the earth round the ſun.

If the hoop be divided into 12 equal parts, d the ſigns be marked in order upon it, be- nning with *Cancer* at the higheſt point of the op, and reckoning eaſtward (or contrary to apparent motion of the ſun) you will ſee w the ſun appears to change his place every y in the ecliptic, as the globe advances eaſt- rd along the hoop, and turns round its own s: and that when the earth is in a low ſign, at *Capricorn*, the ſun muſt appear in a high n, as at *Cancer*, oppoſite to the earth's real ce: and that whilſt the earth is in the thern half of the ecliptic, the ſun appears in northern half, and *vice verſâ*: that the far- r any place is from the equator, between it the polar circle, the greater is the difference ween the longeſt and ſhorteſt day at that ce; and that the poles have but one day and night in the whole year.

Theſe things premiſed, we ſhall proceed to deſcription and uſe of the terreſtrial globe,

 and

and explain the geographical terms as they occur in the problems.

The *terrestrial globe* described.

This globe has the boundaries of land and water laid down upon it, the countries and kingdoms divided by dots, and coloured to distinguish them, the islands properly situated, the rivers and principal towns inserted, as they have been ascertained upon the earth by measurement and observation.

The equator, ecliptic, tropics, polar circles, and meridians, are laid down upon the globe in the manner already described. The ecliptic is divided into 12 signs, and each sign into 30 degrees, which are generally subdivided into halves, and into quarters if the globe is large. Each tropic is $23\frac{1}{2}$ degrees from the equator, and each polar circle $23\frac{1}{2}$ degrees from its respective pole. Circles are drawn parallel to the equator, at every ten degrees distance from it on each side to the poles: these circles are called *parallels of latitude.* On large globes there are circles drawn perpendicularly through every tenth degree of the equator, intersecting each other at the poles: but on globes of or under a foot diameter, they are only drawn through every fifteenth degree of the equator; these circles are generally called *meridians*, sometimes *circles of longitude*, and at other times *hour circles.*

The globe is hung in a brass ring, called the *brasen meridian*; and turns upon a wire in each pole sunk half its thickness into one side of the meridian ring; by which means, *that* side of the ring divides the globe into two equal parts, called the *eastern* and *western hemispheres*; as the equator divides it into two equal parts, called the *northern* and *southern hemispheres.* This ring is divided

divided into 360 equal parts or degrees, on the side wherein the axis of the globe turns. One half of these degrees are numbered, and reckoned, from the equator to the poles, where they end at 90: their use is to shew the latitudes of places. The degrees on the other half of the meridian ring, are numbered from the poles to the equator, where they end at 90: their use is to shew how to elevate either the north or south pole above the horizon, according to the latitude of any given place, as it is north or south of the equator.

The brasen meridian is let into two notches made in a broad flat ring, called the *wooden horizon*, the upper surface of which divides the globe into two equal parts, called the *upper* and *lower hemispheres*. One notch is in the north point of the horizon, and the other in the south. On this horizon are several concentric circles, which contain the months and days of the year, the signs and degrees answering to the sun's place for each month and day, and the 32 points of the compass.—The graduated side of the brass meridian lies towards the east side of the horizon, and should be generally kept toward the person who works problems by the globes.

There is a small *horary circle*, so fixed to the north part of the brasen meridian, that the wire in the north pole of the globe is in the center of that circle; and on the wire is an *index*, which goes over all the 24 hours of the circle, as the globe is turned round its axis. Sometimes there are two horary circles, one between each pole of the globe and the brasen meridian; which is the contrivance of the late ingenious Mr. *Joseph Harris*, master of the assay-office in the Tower of London; and makes it very conve-

nient for putting the poles of the globe through the horizon, and for elevating the pole to small latitudes and declinations of the sun; which cannot be done where there is only one horary circle fixed to the outer edge of the brasen meridian.

There is a thin slip of brass, called the *quadrant of altitude*, which is divided into 90 equal parts or degrees, answering exactly to so many degrees of the equator. It is occasionally fixed to the uppermost point of the brasen meridian by a nut and screw. The divisions end at the nut, and the quadrant is turned round upon it.

As the globe has been seen by most people, and upon the figure of which, in a plate, neither the circles nor countries can be properly expressed, we judge it would signify very little to refer to a figure of it; and shall therefore only give some directions how to choose a globe, and then describe its use.

Directions for choosing of globes.

1. See that the papers be well and neatly pasted on the globes, which you may know, if the lines and circles thereon meet exactly, and continue all the way even and whole; the circles not breaking into several arches, nor the papers either coming short, or lapping over one another.

2. See that the colours be transparent, and not laid too thick upon the globe to hide the names of places.

3. See that the globe hang evenly between the brasen meridian and the wooden horizon; not inclining either to one side or to the other.

4. See that the globe be as close to the horizon and meridian as it conveniently may; otherwise, you will be too much puzzled to find

againſt what part of the globe any degree of the meridian or horizon is.

5. See that the equinoctial line be even with the horizon all around, when the north or ſouth pole is elevated 90 degrees above the horizon.

6. See that the equinoctial line cuts the horizon in the eaſt and weſt points, in all elevations of the pole from 0 to 90 degrees.

7. See that the degree of the braſen meridian marked with 0, be exactly over the equinoctial line of the globe.

8. See that there be exactly half of the braſen meridian above the horizon; which you may know, if you bring any of the decimal diviſions on the meridian to the north point of the horizon, and find their complement to 90 in the ſouth point.

9. See that when the quadrant of altitude is placed as far from the equator, on the braſen meridian, as the pole is elevated above the horizon, the beginning of the degrees of the quadrant reaches juſt to the plane ſurface of the horizon.

10. See that whilſt the index of the hour-circle (by the motion of the globe) paſſes from one hour to another, 15 degrees of the equator paſs under the graduated edge of the braſen meridian.

11. See that the wooden horizon be made ſubſtantial and ſtrong: it being generally obſerved, that in moſt globes, the horizon is the firſt part that fails, on account of its having been made too ſlight.

Directions for uſing them.

In uſing the globes, keep the eaſt ſide of the horizon towards you (unleſs your problem requires the turning of it) which ſide you may know by the word Eaſt upon the horizon; for

then you have the graduated side of the meridian towards you, the quadrant of altitude before you, and the globe divided exactly into two equal parts, by the graduated side of the meridian.

In working some problems, it will be necessary to turn the whole globe and horizon about, that you may look on the west side thereof; which turning will be apt to jog the ball so, as to shift away that degree of the globe which was before set to the horizon or meridian: to avoid which inconvenience, you may thrust in the feather-end of a quill between the ball of the globe and the brasen meridian; which, without hurting the ball, will keep it from turning in the meridian, whilst you turn the west side of the horizon towards you.

PROBLEM I.

*To find the * latitude and † longitude of any given place upon the globe.*

Turn the globe on its axis, until the given place comes exactly under that graduated side of the brasen meridian, on which the degrees are numbered

* The latitude of a place is its distance from the equator, and is north or south, as the place is north or south of the equator. Those who live at the equator have no latitude, because it is there that the latitude begins.

† The longitude of a place is the number of degrees (reckoned upon the equator) that the meridian of the said place is distant from the meridian of any other place from which we reckon, either eastward or westward, for 180 degrees, or half round the globe. The English reckon the longitude from the meridian of London, and the French now reckon it from the meridian of Paris. The meridian of that place, from which the longitude is reckoned, is called

numbered from the equator; and observe what degree of the meridian the place then lies under; which is its latitude, north or south, as the place is north or south of the equator.

The globe remaining in this position, the degree of the equator, which is under the brasen meridian, is the longitude of the place (from the meridian of *London* on the *English* globes) which is east or west, as the place lies on the east or west side of the first meridian of the globe.—All the *Atlantic Ocean*, and *America*, is on the west side of the meridian of *London*; and the greatest part of *Europe*, and of *Africa*, together with all *Asia*, is on the east side of the meridian of *London*, which is reckoned the *first meridian* of the globe by the *English* geographers and astronomers.

PROBLEM II.

The longitude and latitude of a place being given, to find that place on the globe.

Look for the given longitude in the equator (counting it eastward or westward from the first meridian, as it is mentioned to be east or west;) and bring the point of longitude in the equator to the brasen meridian, on that side which is above the south point of the horizon: then count from the equator, on the brasen meridian, to the degree of the given latitude, towards the north or south pole, according as the latitude is north or south; and under that degree of latitude on the meridian, you will have the place required.

called the *first meridian*. The places upon this meridian have no longitude, because it is there that the longitude begins.

PROBLEM III.

To find the difference of longitude, or difference of latitude, between any two given places.

Bring each of these places to the brasen meridian, and see what its latitude is: the lesser latitude subtracted from the greater, if both places are on the same side of the equator, or both latitudes added together, if they are on different sides of it, is the difference of latitude required. And the number of degrees contained between these places, reckoned on the equator, when they are brought separately under the brasen meridian, is their difference of longitude; if it be less than 180: but if more, let it be subtracted from 360, and the remainder is the difference of longitude required. Or,

Having brought one of the places to the brasen meridian, and set the hour-index to XII, turn the globe until the other place comes to the brasen meridian, and the number of hours and parts of an hour, past over by the index, will give the longitude in time; which may be easily reduced to degrees, by allowing 15 degrees for every hour, and one degree for every four minutes.

N. B. When we speak of bringing any place to the brasen meridian, it is the graduated side of the meridian that is meant.

PROB-

PROBLEM IV.

Any place being given, to find all those places that have the same longitude or latitude with it.

Bring the given place to the brasen meridian, then all those places which lie under that side of the meridian, from pole to pole, have the same longitude with the given place. Turn the globe round its axis, and all those places which pass under the same degree of the meridian that the given place does, have the same latitude with that place.

Since all latitudes are reckoned from the equator, and all longitudes are reckoned from the first meridian, it is evident, that the point of the equator which is cut by the first meridian, has neither latitude nor longitude.—The greatest latitude is 90 degrees, because no place is more than 90 degrees from the equator. And the greatest longitude is 180 degrees, because no place is more than 180 degrees from the first meridian.

PROBLEM V.

To find the * antœci, † periœci, *and* ‡ antipodes, *of any given place.*

Bring the given place to the brasen meridian, and having found its latitude, keep the globe in that situation, and count the same number of degrees

* The *antœci* are those people who live on the same meridian, and in equal latitudes, on different sides of the equator. Being on the same meridian, they have the same hours; that is, when it is noon to the one, it is also noon to the other; and when it is mid-night to the one, it is also midnight to the other, &c. Being on different sides of the equator,

degrees of latitude from the equator towards the contrary pole, and where the reckoning ends, you have the *antœci* of the given place upon the globe. Those who live at the equator have no *antœci*.

The globe remaining in the same position, set the hour-index to the upper XII on the horary circle, and turn the globe until the index comes to the lower XII; then, the place which lies under the meridian, in the same latitude with the given place, is the *periœci* required. Those who live at the poles have no *periœci*.

As the globe now stands (with the index at the lower XII) the *antipodes* of the given place will be under the same point of the brasen meridian where its *antœci* stood before. Every place upon the globe has its *antipodes*.

tor, they have different or opposite seasons at the same time; the length of any day to the one is equal to the length of the night of that day to the other; and they have equal elevations of the different poles.

† The *periœci* are those people who live on the same parallel of latitude, but on opposite meridians: so that though their latitude be the same, their longitude differs 180 degrees. By being in the same latitude, they have equal elevations of the same pole (for the elevation of the pole is always equal to the latitude of the place) the same length of days or nights, and the same seasons. But being on opposite meridians, when it is noon to the one, it is mid-night to the other.

‡ The *antipodes* are those who live diametrically opposite to one another upon the globe, standing with feet towards feet, on opposite meridians and parallels. Being on opposite sides of the equator, they have opposite seasons, winter to one, when it is summer to the other; being equally distant from the equator, they have the contrary poles equally elevated above the horizon; being on opposite meridians, when it is noon to the one, it must be mid-night to the other; and as the sun recedes from the one when he approaches to the other, the length of the day to one must be equal to the length of the night at the same time to the other.

PROB-

PROBLEM VI.

find the distance between any two places on the globe.

Lay the graduated edge of the quadrant of itude over both the places, and count the mber of degrees intercepted between them on e quadrant; then multiply these degrees by , and the product will give the distance in ographical miles: but to find the distance in nglish miles, multiply the degrees by 69½, and e product will be the number of miles required. , take the distance betwixt any two places th a pair of compasses, and apply that extent the equator; the number of degrees, intercepted between the points of the compasses, is e distance in degrees of a great circle*; which y be reduced either to geographical miles, or English miles, as above.

* Any circle that divides the globe into two equal parts, alled a *great circle*, as the equator or meridian. Any le that divides the globe into two unequal parts (which y parallel of latitute does) is called a *lesser circle*. Now, ery circle, whether great or small, contains 360 degrees, d a degree upon the equator or meridian contains 60 geophical miles, it is evident, that a degree of longitude upon equator, is longer than a degree of longitude upon any llel of latitude, and must therefore contain a greater numof miles. So that, although all the degrees of latitude are ally long upon an artificial globe (though not precisely so the earth itself) yet the degrees of longitude decrease in th, as the latitude increases, but not in the same propor. The following table shews the length of a degree of itude, in geographical miles, and hundredth parts of a , for every degree of latitude, from the equator to the : a degree on the equator being 60 geographical .

Great circle.

Lesser circle.

PROBLEM VII.

A place on the globe being given, and its diſta from any other place, to find all the other pla upon the globe which are at the ſame diſtance fr the given place.

Bring the given place to the braſen meridi and ſcrew the quadrant of altitude to the me dian, directly over that place; then keeping t globe in that poſition, turn the quadrant qu round upon it, and the degree of the quadra that touches the ſecond place, will paſs over a the other places which are equally diſtant with from the given place.

This is the ſame as if one foot of a pair compaſſes was ſet in the given place, and th other foot extended to the ſecond place, who diſtance is known; for if the compaſſes be the turned round the firſt place as a center, th moving foot will go over all thoſe places whic are at the ſame diſtance with the ſecond from it.

[T]able shewing the **number** *of* **miles** *in* **a degree** *of [lo]ngitude, and in any given degree of latitude.*

D[eg.]	Parts. Miles.	Deg.	Parts. Miles.	Deg.	Parts. Miles.
1	59.99	31	51.43	61	29.09
2	59.96	32	50.88	62	28.17
3	59.92	33	50.32	63	27.24
4	59.85	34	49.74	64	26.30
5	59 77	35	49.15	65	25.36
6	59.67	36	48.54	66	24.41
7	59.56	37	47.92	67	23.44
8	59.42	38	47.28	68	22.48
9	59.26	39	46.63	69	21.50
0	59.09	40	45.97	70	20.52
1	58.89	41	45.28	71	19.53
2	58.69	42	44.59	72	18.54
3	58.46	43	43.88	73	17.54
4	58.22	44	43.16	74	16.53
5	57.95	45	42.43	75	15.52
6	57.67	46	41.68	76	14.51
7	57.38	47	40.92	77	13.50
8	57.06	48	40.15	78	12.48
9	56.73	49	39.36	79	11.45
0	56.38	50	38.57	80	10.42
1	56.02	51	37.76	81	9.38
2	55 63	52	36.94	82	8.35
3	55.23	53	36.11	83	7.32
4	54.81	54	35.27	84	6.28
5	54.38	55	34.41	85	5.24
6	53 93	56	33.55	86	4.20
7	53.46	57	32.68	87	3.15
8	52.96	58	31.79	88	2.10
9	52.47	59	30.90	89	1.05
0	51.96	60	30.00	90	0.00

PROB-

PROBLEM VIII.

The hour of the day at any place being given, to f
all those places where it is noon at that time.

Bring the given place to the brasen meridi and set the index to the given hour; this do turn the globe until the index points to the up XII, and then, all the places that lie under brasen meridian have noon at that time.

N. B. The upper XII always stands for noo and when the bringing of any place to the bra meridian is mentioned, the side of that merid on which the degrees are reckoned from equator is meant, unless the contrary side mentioned.

PROBLEM IX.

The hour of the day at any place being given, to f
what o'clock it then is at any other place.

Bring the given place to the brasen meridi and set the index to the given hour; then t the globe, until the place where the hour is quired comes to the meridian, and the index point out the hour at that place.

PROBLEM X.

*To find the sun's place in the ecliptic, and his**
clination, for any given day of the year.

Look on the horizon for the given day, right against it you have the degree of the in which the sun is (or his place) on that

* The sun's declination is his distance from the equino in degrees, and is north or south, as the sun is between equinoctial and the north or south pole.

at noon. Find the same degree of that sign in the ecliptic line upon the globe, and having brought it to the brasen meridian, observe what degree of the meridian stands over it; for that is the sun's declination, reckoned from the equator.

PROBLEM XI.

The day of the month being given, to find all those places of the earth over which the sun will pass vertically on that day.

Find the sun's place in the ecliptic for the given day, and having brought it to the brasen meridian, observe what point of the meridian is over it; then turning the globe round its axis, all those places which pass under that point of the meridian, are the places required: for as their latitude is equal, in degrees and parts of a degree, to the sun's declination, the sun must be directly over head to each of them at its respective noon.

PROBLEM XII.

*A place being given in the * torrid zone, to find those two days of the year, on which the sun shall be vertical to that place.*

Bring the given place to the brasen meridian, and mark the degree of latitude that is exactly over

* The globe is divided into five zones; one torrid, two temperate, and two frigid. The *torrid zone* lies between the two tropics, and is 47 degrees in breadth, or $23\frac{1}{2}$ on each side of the equator: the *temperate zones* lie between the tropics and polar circles, or from $23\frac{1}{2}$ degrees of latitude, to $66\frac{1}{2}$, on each

over it on the meridian; then turn the globe round its axis, and observe the two degrees of the ecliptic which pass exactly under that degree of latitude: lastly, find on the wooden horizon, the two days of the year on which the sun is in those degrees of the ecliptic, and they are the days required: for on them, and none else, the sun's declination is equal to the latitude of the given place: and consequently, he will then be vertical to it at noon.

PROBLEM XIII.

To find all those places of the north frigid zone, where the sun begins to shine constantly without setting, on any given day, from the 21st of March to the 23d of September.

On these two days, the sun is in the equinoctial, and enlightens the globe exactly from pole to pole: therefore, as the earth turns round its axis, which terminates in the poles, every place upon it will go equally through the light and the dark, and so make the day and night equal to all places of the earth. But as the sun declines from the equator, towards either pole, he will shine just as many degrees round that pole, as are equal to his declination from the equator; so that no place within that distance of the pole will then go through any part of the dark, and consequently the sun will not set to it. Now, as

each side of the equator; and are each 43 degrees in breadth: the *frigid zones* are the spaces included within the polar circles, which being each $23\frac{1}{2}$ degrees from their respective poles, the breadth of each of these zones is 47 degrees. As the sun never goes without the tropics, he must every moment be vertical to some place or other in the torrid zone.

the sun's declination is northward, from the 21st of March to the 23d of September, he must constantly shine round the north pole all that time; and on the day that he is in the northern tropic, he shines upon the whole north frigid zone; so that no place within the north polar circle goes through any part of the dark on that day. Therefore,

Having brought the sun's place for the given day to the brasen meridian, and found his declination (by Prob. IX.) count as many degrees on the meridian, from the north pole, as are equal to the sun's declination from the equator, and mark that degree from the pole where the reckoning ends: then, turning the globe round its axis, observe what places in the north frigid zone pass directly under that mark; for they are the places required.

The like may be done for the south frigid zone, from the 23d of September to the 21st of March, during which time the sun shines constantly on the south pole.

PROBLEM XIV.

To find the place over which the sun is vertical, at any hour of a given day.

Having found the sun's declination for the given day (by Prob. IX.) mark it with a chalk on the brasen meridian: then bring the place where you are (suppose London) to the brasen meridian, and set the index to the given hour; which done turn the globe on its axis, until the index points to XII at noon; and the place on the globe, which is then directly under the point

of the ſun's declination marked upon the meridian, has the ſun that moment in the zenith, or directly overhead.

PROBLEM XV.

The day and hour at any place being given, to find all thoſe places where the ſun is then riſing, or ſetting, or on the meridian: conſequently, all thoſe places which are enlightened at that time, and thoſe which are in the dark.

This problem cannot be ſolved by any globe fitted up in the common way, with the hour circle fixed upon the braſs meridian; unleſs the ſun be on or near ſome of the tropics on the given day. But by a globe fitted up according to Mr. *Joſeph Harris*'s invention (already mentioned) where the hour-circle lies on the ſurface of the globe, below the meridian, it may be ſolved for any day in the year, according to his method; which is as follows.

Having found the place to which the ſun is vertical at the given hour, if the place be in the northern hemiſphere, elevate the north pole as many degrees above the horizon, as are equal to the latitude of that place; if the place be in the ſouthern hemiſphere, elevate the ſouth pole accordingly; and bring the ſaid place to the braſen meridian. Then, all thoſe places which are in the weſtern ſemicircle of the horizon, have the ſun riſing to them at that time; and thoſe in the eaſtern ſemicircle have it ſetting: to thoſe under the upper ſemicircle of the braſs meridian, it is noon; and to thoſe under the lower ſemicircle, it is mid-night. All thoſe places which are above the horizon, are enlightened by the ſun, and

and have the ſun juſt as many degrees above them, as they themſelves are above the horizon: and this height may be known, by fixing the quadrant of altitude on the braſen meridian over the place to which the ſun is vertical; and then, laying it over any other place, obſerve what number of degrees on the quadrant are intercepted between the ſaid place and the horizon. In all thoſe places that are 18 degrees below the weſtern ſemicircle of the horizon, the morning twilight is juſt beginning; in all thoſe places that are 18 degrees below the eaſtern ſemicircle of the horizon, the evening twilight is ending; and all thoſe places that are lower than 18 degrees, have dark night.

If any place be brought to the upper ſemicircle of the braſen meridian, and the hour index be ſet to the upper XII or noon, and then the globe be turned round eaſtward on its axis; when the place comes to the weſtern ſemicircle of the horizon, the index will ſhew the time of ſun-riſing at that place; and when the ſame place comes to the eaſtern ſemicircle of the horizon, the index will ſhew the time of ſun-ſet.

To thoſe places which do not go under the horizon, the ſun ſets not on that day: and to thoſe which do not come above it, the ſun does not riſe.

PROBLEM XVI.

The day and hour of a lunar eclipſe being given, to find all thoſe places of the earth to which it will be viſible.

The moon is never eclipſed but when ſhe is full, and ſo directly oppoſite to the ſun, that the

earth's shadow falls upon her. Therefore, whatever place of the earth the sun is vertical to at that time, the moon must be vertical to the antipodes of that place: so that the sun will be then visible to one half of the earth, and the moon to the other.

Find the place to which the sun is vertical at the given hour (by Prob. XIV.) elevate the pole to the latitude of that place, and bring the place to the upper part of the brasen meridian, as in the former problem: then, as the sun will be visible to all those parts of the globe which are above the horizon, the moon will be visible to all those parts of the globe which are below it, at the time of her greatest obscuration.

But with regard to an eclipse of the sun, there is no such thing as shewing to what places it will be visible, with any degree of certainty, by a common globe; because the moon's shadow covers but a small portion of the earth's surface, and her latitude, or declination from the ecliptic, throws her shadow so variously upon the earth, that to determine the places on which it falls, recourse must be had to long calculations.

PROBLEM XVII.

*To rectify the globe for the latitude, the * zenith, and the sun's place.*

Find the latitude of the place (by Prob. I.) and if the place be in the northern hemisphere, raise the north pole above the north point of the horizon,

* The *zenith*, in this sense, is the highest point of the brasen meridian above the horizon; but in the proper sense, it is that point of the heaven which is directly vertical to any given place, at any given instant of time.

as many degrees (counted from the pole upon the brasen meridian) as are equal to the latitude of the place. If the place be in the southern hemisphere, raise the south pole above the south point of the horizon, as many degrees as are equal to the latitude. Then, turn the globe till the place comes under its latitude on the brasen meridian, and fasten the quadrant of altitude so, that the chamfered edge of its nut (which is even with the graduated edge) may be joined to the zenith, or point of latitude. This done, bring the sun's place in the ecliptic for the given day, (found by Prob. X.) to the graduated side of the brasen meridian, and set the hour-index to XII at noon, which is the uppermost XII on the hour-circle; and the globe will be rectified.

Remark. The latitude of any place, is equal to the elevation of the nearest pole of the heaven above the horizon of that place; and the poles of the heaven are directly over the poles of the earth, each 90 degrees from the equinoctial line. Let us be upon what place of the earth we will, if the limits of our view be not intercepted by hills, we shall see one half of the heaven, or 90 degrees every way round, from that point which is over our heads. Therefore, if we were upon the equator, the poles of the heaven would lie in our horizon, or limit of our view: if we go from the equator, towards either pole of the earth, we shall see the corresponding pole of the heaven rising gradually above our horizon, just as many degrees as we have gone from the equator: and if we were at either of the earth's poles, the corresponding pole of the heaven would be directly over our head. Consequently, the elevation or height of the pole in

degrees above the horizon, is equal to the number of degrees that the place is from the equator.

PROBLEM XVIII.

The latitude of any place, not exceeding * 66½ *degrees, and the day of the month, being given; to find the time of sun-rising and setting, and consequently the length of the day and night.*

Having rectified the globe for the latitude, and for the sun's place on the given day (as directed in the preceding problem) bring the sun's place in the ecliptic to the eastern side of the horizon, and the hour-index will shew the time of sun-rising; then turn the globe on its axis, until the sun's place comes to the western side of the horizon, and the index will shew the time of sun setting.

The hour of sun-setting doubled, gives the length of the day; and the hour of sun-rising doubled gives the length of the night.

PROBLEM XIX.

The latitude of any place, and the day of the month, being given; to find when the morning twilight begins, and the evening twilight ends, at that place.

This problem is often limited; for, when the sun does not go 18 degrees below the horizon, the twilight continues the whole night; and for

* All places whose latitude is more than 66½ degrees, are in the frigid zones: and to those places the sun does not set in summer, for a certain number of diurnal revolutions, which occasions this limitation of latitude.

several

ſeveral nights together in ſummer, between 49 and $66\frac{1}{2}$ degrees of latitude: and the nearer to $66\frac{1}{2}$, the greater is the number of theſe nights. But when it does begin and end, the following method will ſhew the time for any given day.

Rectify the globe, and bring the ſun's place in the ecliptic to the eaſtern ſide of the horizon; then mark that point of the ecliptic with a chalk which is in the weſtern ſide of the horizon, it being the point oppoſite to the ſun's place: this done, lay the quadrant of altitude over the ſaid point, and turn the globe eaſtward, keeping the quadrant at the chalk-mark, until it is juſt 18 degrees high on the quadrant; and the index will point out the time when the morning twilight begins: for the ſun's place will then be 18 degrees below the eaſtern ſide of the horizon. To find the time when the evening twilight ends, bring the ſun's place to the weſtern ſide of the horizon, and the point oppoſite to it, which was marked with the chalk, will be riſing in the eaſt: then, bring the quadrant over that point, and keeping it thereon, turn the globe weſtward, until the ſaid point be 18 degrees above the horizon on the quadrant, and the index will ſhew the time when the evening twilight ends; the ſun's place being then 18 degrees below the weſtern ſide of the horizon.

PROBLEM XX.

To find on what day of the year the sun begins to shine constantly without setting, on any given place in the north frigid zone; and how long he continues to do so.

Rectify the globe to the latitude of the place, and turn it about until some point of the ecliptic, between *Aries* and *Cancer*, coincides with the north point of the horizon where the brasen meridian cuts it: then find, on the wooden horizon, what day of the year the sun is in that point of the ecliptic; for that is the day on which the sun begins to shine constantly on the given place, without setting. This done, turn the globe until some point of the ecliptic, between *Cancer* and *Libra*, coincides with the north point of the horizon, where the brasen meridian cuts it; and find, on the wooden horizon, on what day the sun is in that point of the ecliptic; which is the day that the sun leaves off constantly shining on the said place, and rises and sets to it as to other places on the globe. The number of natural days, or compleat revolutions of the sun about the earth, between the two days above found, is the time that the sun keeps constantly above the horizon without setting: for all the portion of the ecliptic, which lies between the two points which intersect the horizon in the very north, never sets below it: and there is just as much of the opposite part of the ecliptic that never rises; therefore, the sun will keep as long constantly below the horizon in winter, as above it in summer.

Whoever

Whoever considers the globe, will find, that all places of the earth do equally enjoy the benefit of the sun, in respect of time, and are equally deprived of it. For, the days and nights are always equally long at the equator: and in all places that have latitude, the days at one time of the year are exactly equal to the nights at the opposite season.

PROBLEM XXI.

To find in what latitude the sun shines constantly without setting, for any length of time less than * 182½ *of our days and nights.*

Find a point in the ecliptic half as many degrees from the beginning of *Cancer* (either toward *Aries* or *Libra*) as there are † natural days in the time given; and bring that point to the north side of the brasen meridian, on which the degrees are numbered from the pole towards the equator: then, keep the globe from turning on its axis, and slide the meridian up or down, until the foresaid point of the ecliptic comes to the north point of the horizon, and then, the elevation of the pole will be equal to the latitude required.

* The reason of this limitation is, that 182½ of our days and nights make half a year, which is the longest time that the sun shines without setting, even at the poles of the earth.

† A natural day contains the whole 24 hours: an artificial day, the time that the sun is above the horizon.

PROBLEM XXII.

The latitude of a place, not exceeding 66½ degrees, and the day of the month being given; to find the sun's amplitude, or point of the compass on which he rises or sets.

Rectify the globe, and bring the sun's place to the eastern side of the horizon; then observe what point of the compass on the horizon stands right against the sun's place, for that is his amplitude at rising. This done, turn the globe westward, until the sun's place comes to the western side of the horizon, and it will cut the point of his amplitude at setting. Or, you may count the rising amplitude in degrees, from the east point of the horizon, to that point where the sun's place cuts it; and the setting amplitude, from the west point of the horizon, to the sun's place at setting.

PROBLEM XXIII.

*The latitude, the sun's place, and his * altitude, being given; to find the hour of the day, and the sun's azimuth, or number of degrees that he is distant from the meridian.*

Rectify the globe, and bring the sun's place to the given height upon the quadrant of altitude; on the eastern side of the horizon, if the time be in the forenoon; or the western side, if

* The sun's altitude, at any time, is his height above the horizon at that time.

it be in the afternoon: then, the index will ſhew the hour; and the number of degrees in the horizon, intercepted, between the quadrant of altitude and the ſouth point, will be the ſun's true azimuth at that time.

N. B. Always when the quadrant of altitude is mentioned in working any problem, the graduated edge of it is meant.

If this be done at ſea, and compared with the ſun's azimuth, as ſhewn by the compaſs, if they agree, the compaſs has no variation in that place: but if they differ, the compaſs does vary; and the variation is equal to this difference.

PROBLEM XXIV.

The latitude, hour of the day, and the ſun's place, being given; to find the ſun's altitude and azimuth.

Rectify the globe, and turn it until the index points to the given hour; then lay the quadrant of altitude over the ſun's place in the ecliptic, and the degree of the quadrant cut by the ſun's place in his altitude at that time above the horizon; and the degree of the horizon cut by the quadrant is the ſun's azimuth, reckoned from the ſouth.

PRO-

PROBLEM XXV.

The latitude, the sun's altitude, and his azimuth being given; to find his place in the ecliptic, the day of the month, and hour of the day, though they had all been lost.

Rectify the globe for the latitude and † zenith, and set the quadrant of altitude to the given azimuth in the horizon; keeping it there, turn the globe on its axis until the ecliptic cuts the quadrant in the given altitude: that point of the ecliptic which cuts the quadrant there, will be the sun's place; and the day of the month answering thereto, will be found over the like place of the sun on the wooden horizon. Keep the quadrant of altitude in that position, and having brought the sun's place to the brasen meridian, and the hour index to XII at noon, turn back the globe, until the sun's place cuts the quadrant of altitude again, and the index will shew the hour.

Any two points of the ecliptic which are equidistant from the beginning of *Cancer* or of *Capricorn*, will have the same altitude and azimuth at the same hour, though the months be different; and therefore it requires some care in this problem, not to mistake both the month, and the day of the month; to avoid which, observe, that from the 20th of March to the 21st of June, that part of the ecliptic which is

† By rectifying the globe for the zenith, is meant screwing the quadrant of altitude to the given latitude on the brass meridian.

between

between the beginning of *Aries* and beginning of *Cancer* is to be used: from the 21st of June to the 23d of September, between the beginning of *Cancer* and beginning of *Libra:* from the 23d of September to the 21st of December, between the beginning of *Libra* and the beginning of *Capricorn*; and from the 21st of December to the 20th of March, between the beginning of *Capricorn* and beginning of *Aries*. And as one can never be at a loss to know in what quarter of the year he takes the sun's altitude and azimuth, the above caution with regard to the quarters of the ecliptic, will keep him right as to the month and day thereof.

PROBLEM XXVI.

To find the length of the longest day at any given place.

If the place be on the north side of the equator, find its latitude (by Prob. I.) and elevate the north pole to that latitude; then, bring the beginning of *Cancer* ♋ to the brasen meridian, and set the hour-index to XII at noon. But if the given place be on the south side of the equator, elevate the south pole to its latitude, and bring the beginning of *Capricorn* ♑ to the brass meridian, and the hour-index to XII. This done, turn the globe westward, until the beginning of *Cancer* or *Capricorn* (as the latitude is north or south) comes to the horizon; and the index will then point out the time of sun-setting, for it will have gone over all the afternoon hours, between mid-day and sun-set;

† which

which length of time being doubled, will give the whole length of the day, from ſun-riſing to ſun-ſetting. For, in all latitudes, the ſun riſes as long before mid-day, as he ſets after it.

PROBLEM XXVII.

To find in what latitude the longeſt day is of any given length leſs than 24 hours.

If the latitude be north, bring the beginning of *Cancer* to the braſen meridian, and elevate the north pole to about $66\frac{1}{2}$ degrees; but if the latitude be ſouth, bring the beginning of *Capricorn* to the meridian, and elevate the ſouth pole to about $66\frac{1}{2}$ degrees; becauſe the longeſt day in north latitude, is when the ſun is in the firſt point of *Cancer*; and in ſouth latitude, when he is in the firſt point of *Capricorn.* Then ſet the hour-index to XII at noon, and turn the globe weſtward, until the index points at half the number of hours given; which done, keep the globe from turning on its axis, and ſlide the meridian down in the notches, until the aforeſaid point of the ecliptic (viz. *Cancer* or *Capricorn)* comes to the horizon; then, the elevation of the pole will be equal to the latitude required.

PRO-

PROBLEM XXVIII.

*The latitude of any place, not exceeding 66½ degrees, being given; to find in what * climate the place is.*

Find the length of the longest day at the given place by Prob. XXVI. and whatever be the number of hours whereby it exceedeth twelve, double that number, and the sum will give the climate in which the place is.

PROBLEM XXIX.

The latitude, and the day of the month, being given; to find the hour of the day when the sun shines.

Set the wooden horizon truly level, and the brasen meridian due north and south by a mariner's compass: then, having rectified the globe, stick a small sewing-needle into the sun's place in the ecliptic, perpendicular to that part of the surface of the globe: this done, turn the globe on its axis, until the needle comes to the brasen meridian, and set the hour-index to XII

* A *climate*, from the equator to either of the polar circles, is a tract of the earth's surface, included between two such parallels of latitude, that the length of the longest day in the one exceeds that in the other by half an hour; but from the polar circles to the poles, where the sun keeps long above the horizon without setting, each climate differs a whole month from the one next to it. There are twenty-four climates between the equator and each of the polar circles; and six from each polar circle to its respective pole.

at

at noon; then, turn the globe on its axis, until the needle points exactly towards the sun (which it will do when it casts no shadow on the globe) and the index will shew the hour of the day.

PROBLEM XXX.

A pleasant way of shewing all those places of the earth which are enlightened by the sun, and also the time of the day when the sun shines.

Take the terrestrial ball out of the wooden horizon, and also out of the brasen meridian; then set it upon a pedestal in sun-shine, in such a manner, that its north pole may point directly towards the north pole of the heaven, and the meridian of the place where you are be directly towards the south. Then, the sun will shine upon all the like places of the globe, that he does on the real earth, rising to some when he is setting to others; as you may perceive by that part where the enlightened half of the globe is divided from the half in the shade, by the boundary of the light and darkness: all those places, on which the sun shines, at any time, having day; and all those, on which he does not shine, having night.

If a narrow slip of paper be put round the equator, and divided into 24 equal parts, beginning at the meridian of your place, and the hours be set to those divisions in such a manner, that one of the VI's may be upon your meridian; the sun being upon that meridian at noon, will then shine exactly to the two XII's; and at one o'clock to the two I's, &c. So that the place,

place, where the enlightened half of the globe is parted from the shaded half, in this circle of hours, will shew the hour of the day.

The principles of dialing shall be explained farther on, by the terrestrial globe. At present we shall only add the following observations upon it; and then proceed to the use of the celestial globe.

1. *The latitude of any place is equal to the elevation of the pole above the horizon of that place, and the elevation of the equator is equal to the complement of the latitude, that is, to what the latitude wants of* 90 *degrees.*

2. *Those places which lie on the equator, have no latitude, it being there that the latitude begins; and those places which lie on the first meridian have no longitude, it being there that the longitude begins. Consequently,* that *particular place of the earth where the first meridian intersects the equator, has neither longitude nor latitude.*

3. *In all places of the earth, except the poles, all the points of the compass may be distinguished in the horizon: but from the north pole, every place is south; and from the south pole, every place is north. Therefore, as the sun is constantly above the horizon of each pole for half a year in its turn, it cannot be said to depart from the meridian of either pole for half a year together. Consequently, at the north pole it may be said to be noon every moment for half a year; and let the winds blow from what part they will, they must always blow from the south; and at the south pole, from the north.*

4. *Because one half of the ecliptic is above the horizon of the pole, and the sun, moon and planets, move in (or nearly in) the ecliptic; they will all*

rise and set to the poles. But, because the sta[rs] never change their declinations from the equator (a[t] least not sensibly in one age) those which are onc[e] above the horizon of either pole, never set below it; and those which are once below it, never rise.

5. *All places of the earth do equally enjoy the be[-] nefit of the sun, in respect of time, and are equall[y] deprived of it.*

6. *All places upon the equator have their day[s] and nights equally long, that is,* 12 *hours each, a[t] all times of the year. For although the sun declin[es] alternately, from the equator towards the north a[nd] towards the south, yet, as the horizon of the equ[a-] tor cuts all the parallels of latitude and declinati[on] in halves, the sun must always continue above th[e] horizon for one half a diurnal revolution about th[e] earth, and for the other half below it.*

7. *When the sun's declination is greater than t[he] latitude of any place, upon either side of the equat[or,] the sun will come twice to the same azimuth or poi[nt] of the compass in the forenoon, at that place, a[nd] twice to a like azimuth in the afternoon; that i[s,] he will go twice back every day, whilst his declin[a-] tion continues to be greater than the latitude. Th[us,] suppose the globe rectified to the latitude of Barb[a-] does, which is* 13 *degrees north; and the sun to [be] any where in the ecliptic, between the middl[e of] Taurus and middle of Leo; if the quadrant of [al-] titude be set to about* † 18 *degrees north of the e[ast] in the horizon, the sun's place be marked wit[h] chalk upon the ecliptic, and the globe be then tur[ned] westward on its axis, the said mark will rise in [the] horizon a little to the north of the quadrant, [and] thence ascending, it will cross the quadrant tow[ards]*

† From the middle of Gemini to the middle of Ca[ncer] the quadrant may be set 20 degrees.

the south; but before it arrives at the meridian, it will cross the quadrant again, and pass over the meridian northward of Barbadoes. And if the quadrant be set about 18 *degrees north of the west, the sun's place will cross it twice, as it descends from the meridian towards the horizon, in the afternoon.*

8. *In all places of the earth between the equator and poles, the days and nights are equally long, viz.* 12 *hours each, when the sun is in the equinoctial: for, in all elevations of the pole, short of* 90 *degrees (which is the greatest) one half of the equator or equinoctial will be above the horizon, and the other half below it.*

9. *The days and nights are never of an equal length at any place between the equator and polar circles, but when the sun enters the signs ♈ Aries and ♎ Libra. For in every other part of the ecliptic, the circle of the sun's daily motion is divided into two unequal parts by the horizon.*

10. *The nearer that any place is to the equator, the less is the difference between the length of the days and nights in that place; and the more remote, the contrary. The circles which the sun describes in the heaven every* 24 *hours, being cut more nearly equal in the former case, and more unequally in the latter.*

11. *In all places lying upon any given parallel of latitude, however long or short the day or night be at any one of these places, at any time of the year, it is then of the same length at all the rest; for in turning the globe round its axis (when rectified according to the sun's declination) all these places will keep equally long above or below the horizon.*

12. *The sun is vertical twice a year to every place between the tropics; to those under the tropics,*

once a year, but never any where else. For there can be no place between the tropics, but that there will be two points in the ecliptic, whose declination from the equator is equal to the latitude of that place; and but one point of the ecliptic which has a declination equal to the latitude of places on the tropic which that point of the ecliptic touches; and as the sun never goes without the tropics, he can never be vertical to any place that lies without them.

13. *To all places in the * torrid zone, the duration of the twilight is least, because the sun's daily motion is the most perpendicular to the horizon. In the frigid † zones, greatest; because the sun's daily motion is nearly parallel to the horizon; and therefore he is the longer of getting 18 degrees below it (till which time the twilight always continues.) And in the ‡ temperate zones it is at a medium between the two, because the obliquity of the sun's daily motion is so.*

14. *In all places lying exactly under the polar circles, the sun, when he is in the nearest tropic, continues 24 hours above the horizon without setting; because no part of that tropic is below their horizon. And when the sun is in the farthest tropic, he is for the same length of time without rising; because no part of that tropic is above their horizon. But, at all other times of the year, he rises and sets there, as in other places; because all the circles that can be drawn parallel to the equator, between the tropics, are more or less cut by the horizon, as they are farther from, or nearer to, that tropic which is all above the horizon: and*

* Between the tropics.
† Between the polar circles and poles.
‡ Between the tropics and polar circles.

when

when the sun is not in either of the tropics, his diurnal course must be in one or other of these circles.

15. *To all places in the northern hemisphere, from the equator to the polar circle, the longest day and shortest night is when the sun is in the northern tropic; and the shortest day and longest night is when the sun is in the southern tropic; because no circle of the sun's daily motion is so much above the horizon, and so little below it, as the northern tropic; and none so little above it, and so much below it, as the southern. In the southern hemisphere, the contrary.*

16. *In all places between the polar circles and poles, the sun appears for some number of days (or rather diurnal revolutions) without setting; and at the opposite time of the year without rising; because some part of the ecliptic never sets in the former case, and as much of the opposite part never rises in the latter. And the nearer unto, or the more remote from the pole, these places are, the longer or shorter is the sun's continuing presence or absence.*

17. *If a ship sets out from any port, and sails round the earth eastward to the same port again, let her take what time she will to do it in, the people in that ship, in reckoning their time, will gain one compleat day at their return, or count one day more than those who reside at the same port; because, by going contrary to the sun's diurnal motion, and being forwarder every evening than they were in the morning, their horizon will get so much the sooner above the setting sun, than if they had kept for a whole day at any particular place. And thus, by cutting off a part proportionable to their own motion, from the length of every day, they will gain a compleat day of that sort at their return; without gaining one moment of absolute time more*

 than

than is elapsed during their course, to the people at the port. If they sail westward, they will reckon one day less than the people do who reside at the said port, because by gradually following the apparent diurnal motion of the sun, they will keep him each particular day so much longer above their horizon, as answers to that day's course; and by that means, they cut off a whole day in reckoning, at their return, without losing one moment of absolute time.

Hence, if two ships should set out at the same time from any port, and sail round the globe, one eastward and the other westward, so as to meet at the same port on any day whatever; they will differ two days in reckoning their time, at their return. If they sail twice round the earth, they will differ four days; if thrice, then six, &c.

LECT. IX.

The use of the celestial globe, and armillary sphere.

The *celestial globe.* HAVING done for the present with the terrestrial globe, we shall proceed to the use of the celestial; first premising, that as the equator, ecliptic, tropics, polar circles, horizon, and brasen meridian, are exactly alike on both globes, all the former problems concerning the sun are solved the same way by both globes. The method also of rectifying the celestial globe is the same as rectifying the terrestrial, viz. Elevate the pole according to the latitude of your place, then screw the quadrant of altitude to the zenith, on the brass meridian; bring the sun's place in the ecliptic to the graduated edge of the brass meridian, on the

To rectify it.

side

side which is above the south point of the wooden horizon, and set the hour-index to the uppermost XII, which stands for noon.

N. B. The sun's place for any day of the year stands directly over that day on the horizon of the celestial globe, as it does on that of the terrestrial.

The *latitude* and *longitude* of the stars, and of all other celestial phenomena, are reckoned in a very different manner from the latitude and longitude of places on the earth: for all terrestrial latitudes are reckoned from the equator; and longitudes from the meridian of some remarkable place, as of London by the English, and of Paris by the French; though most of the French maps begin their longitude at the meridian of the island *Ferro.*——But the astronomers of all nations agree in reckoning the *latitudes* of the moon, stars, planets, and comets, from the *ecliptic*; and their *longitudes* from the * *equinoctial colure*, in that semicircle of it which cuts the ecliptic at the beginning of *Aries* ♈; and thence eastward, quite round, to the same semicircle again. Consequently those stars which lie between the equinoctial and the northern half of the ecliptic, have north declination and south latitude; those which lie between the equinoctial and the southern half of the ecliptic, have south declination and north latitude; and *Latitude and longitude of the stars.*

* *The great circle* that passes through the *equinoctial points* at the beginning of ♈ and ♎, and through the *poles of the world* (which are two opposite points, each 90 degrees from the equinoctial) is called the *equinoctial colure*: and the *great circle* that passes through the *beginning of* ♋ and ♑, and also through the *poles of the ecliptic*, and poles of the world, is called the *solstitial colure*. *Colures.*

 all

all those which lie between the tropics and poles, have their declinations and latitudes of the same denomination.

There are six great circles on the celestial globe, which cut the ecliptic perpendicularly, and meet in two opposite points in the polar circles; which points are each ninety degrees from the ecliptic, and are called its poles. These polar points divide those circles into 12 semicircles; which cut the ecliptic at the beginnings of the 12 signs. They resemble so many meridians on the terrestrial globe; and as all places which lie under any particular meridian semicircle on that globe, have the same longitude, so all those points of the heaven, through which any one of the above semicircles are drawn, have the same longitude.—And as the greatest latitudes on the earth are at the north and south poles of the earth, so the greatest latitudes in the heaven, are at the north and south poles of the ecliptic.

Constellations. In order to distinguish the stars, with regard to their situations and positions in the heaven, the antients divided the whole visible firmament of stars into particular systems, which they called *constellations*; and digested them into the forms of such animals as are delineated upon the celestial globe. And those stars which lie between the figures of those imaginary animals, and could not be brought within the compass of any of them, were called *unformed stars*.

Because the moon and all the planets were observed to move in circles or orbits which cross the ecliptic (or line of the sun's path) at small angles, and to be on the north side of the ecliptic for one half of their course round the heaven of stars, and on the south side of it for the other

other half, but never to go quite 8 degrees from it on either side, the antients distinguished that space by two lesser circles, parallel to the ecliptic (one on each side) at 8 degrees distance from it. And the space included between these circles, they called the *zodiac*, because most of the 12 constellations placed therein resemble some living creature.—These constellations are, 1. *Aries* ♈, the ram; 2. *Taurus* ♉, the bull; 3. *Gemini* ♊, the twins; 4. *Cancer* ♋, the crab; 5. *Leo* ♌, the lion; 6. *Virgo* ♍, the virgin; 7. *Libra* ♎, the balance; 8. *Scorpio* ♏, the scorpion; 9. *Sagittarius* ♐, the archer; 10. *Capricornus* ♑, the goat; 11. *Aquarius* ♒, the water bearer; and 12. *Pisces* ♓, the fishes.

Its signs, or divisions.

It is to be observed, that in the infancy of astronomy, these twelve constellations stood at or near the places of the ecliptic, where the above characteristics are marked upon the globe: but now, each constellation has got a whole sign forwarder, on account of the recession of the equinoctial points from their former places. So that the constellation of *Aries*, is now in the former place of *Taurus*; that of *Taurus*, in the former place of *Gemini*; and so on.

Remark.

The stars appear of different magnitudes to the eye; probably because they are at different distances from us. Those which appear brightest and largest, are called *stars of the first magnitude*; the next to them in size and lustre, are called *stars of the second magnitude*; and so on to the *sixth*, which are the smallest that can be discerned by the bare eye.

Some of the most remarkable stars have names given them, as *Castor* and *Pollux* in the heads of the *Twins*, *Sirius* in the mouth of the *Great Dog*, *Procyon* in the side of the *Little Dog*, *Rigel* in

in the left foot of *Orion*, *Arcturus* near the right thigh of *Bootes*, &c.

These things being premised, which I think are all that the young *Tyro* need be acquainted with, before he begins to work any problem by this globe, we shall now proceed to the most useful of those problems; omitting several which are of little or no consequence.

PROBLEM I.

To find the * *right ascension and* † *declination of the sun, or any fixed star.*

Bring the sun's place in the ecliptic to the brasen meridian, then that degree in the equinoctial which is cut by the meridian, is the sun's *right ascension*; and that degree of the meridian which is over the sun's place, is his *declination*. Bring any fixed star to the meridian, and its *right ascension* will be cut by the meridian in the equinoctial; and the degree of the meridian that stands over it, is its *declination*.

So that *right ascension* and *declination*, on the celestial globe, are found in the same manner as *longitude* and *latitude* on the terrestrial.

* The degree of the equinoctial, reckoned from the beginning of *Aries*, that comes to the meridian with the sun or star, is its *right ascension*.

† The distance of the sun or star in degrees from the equinoctial, towards either of the poles, north or south, is its declination, which is north or south accordingly.

PROBLEM II.

To find the latitude and longitude of any star.

If the given star be on the north side of the ecliptic, place the 90th degree of the quadrant of altitude on the north pole of the ecliptic, where the twelve semicircles meet; which divide the ecliptic into the 12 signs: but if the star be on the south side of the ecliptic, place the 90th degree of the quadrant on the south pole of the ecliptic: keeping the 90th degree of the quadrant on the proper pole, turn the quadrant about, until its graduated edge cuts the star: then, the number of degrees in the quadrant, between the ecliptic and the star, is its latitude; and the degree of the ecliptic cut by the quadrant is the star's longitude, reckoned according to the sign in which the quadrant then is.

PROBLEM III.

To represent the face of the starry firmament, as seen from any given place of the earth, at any hour of the night.

Rectify the celestial globe for the given latitude, the zenith, and sun's place, in every respect, as taught by the 17th problem, for the terrestrial; and turn it about, until the index points to the given hour: then, the upper hemisphere of the globe will represent the visible half of the heaven for that time: all the stars upon

upon the globe being then in such situations, as exactly correspond to those in the heaven. And if the globe be placed duly north and south, by means of a small sea- compass, every star on the globe will point toward the like star in the heaven: by which means, the constellations and remarkable stars may be easily known. All those stars which are in the eastern side of the horizon, are then rising in the eastern side of the heaven; all in the western, are setting in the western side; and all those under the upper part of the brasen meridian, between the south point of the horizon and the north pole, are at their greatest altitude, if the latitude of the place be north: but if the latitude be south, those stars which lie under the upper part of the meridian, between the north point of the horizon and the south pole, are at their greatest altitude.

PROBLEM IV.

The latitude of the place, and day of the month being given; to find the time when any known star will rise, or be on the meridian, or set.

Having rectified the globe, turn it about until the given star comes to the eastern side of the horizon, and the index will shew the time of the star's rising; then turn the globe westward, and when the star comes to the brasen meridian, the index will shew the time of the star's coming to the meridian of your place; lastly, turn on until the star comes to the western side of the horizon, and the index will shew the time of the star's setting.

N. B.

N. B. In northern latitudes, those stars which are less distant from the north pole, than the quantity of its elevation above the north point of the horizon, never set; and those which are less distant from the south pole, than the number of degrees by which it is depressed below the horizon, never rise: and *vice versâ* in southern latitudes.

PROBLEM V.

To find at what time of the year a given star will be upon the meridian, at a given hour of the night.

Bring the given star to the upper semicircle of the brass meridian, and set the index to the given hour; then turn the globe, until the index points to XII at noon, and the upper semicircle of the meridian will then cut the sun's place, answering to the day of the year sought; which day may be easily found against the like place of the sun among the signs on the wooden horizon.

PROBLEM VI.

*The latitude, day of the month, and * azimuth of any known star being given; to find the hour of the night.*

Having rectified the globe for the latitude, zenith, and sun's place; lay the quadrant of altitude

* The number of degrees that the sun, moon, or any star, is from the meridian, either to the east or west, is called its *azimuth*.

altitude to the given degree of azimuth in the horizon: then turn the globe on its axis, until the star comes to the graduated edge of the quadrant; and when it does, the index will point out the hour of the night.

PROBLEM VII.

*The latitude of the place, the day of the month, and altitude * of any known star, being given; to find the hour of the night.*

Rectify the globe as in the former problem, guess at the hour of the night, and turn the globe until the index points at the supposed hour; then lay the graduated edge of the quadrant of altitude over the known star, and if the degree of the star's height in the quadrant upon the globe, answers exactly to the degree of the star's observed altitude in the heaven, you have guessed exactly: but if the star on the globe is higher or lower than it was observed to be in the heaven, turn the globe backwards or forwards, keeping the edge of the quadrant upon the star, until its center comes to the observed altitude in the quadrant; and then, the index will shew the true time of the night.

* The number of degrees that the star is above the horizon, as observed by means of a common quadrant, is called its *altitude*.

PRO-

PROBLEM VIII.

An easy method for finding the hour of the night by any two known stars, without knowing either their altitude or azimuth; and then, of finding both their altitude and azimuth, and thereby the true meridian.

Tie one end of a thread to a common musket bullet; and, having rectified the globe as above, hold the other end of the thread in your hand, and carry it slowly round betwixt your eye and the starry heaven, until you find it cuts any two known stars at once. Then, guessing at the hour of the night, turn the globe until the index points to that time in the hour-circle; which done, lay the graduated edge of the quadrant over any one of these two stars on the globe, which the thread cut in the heaven. If the said edge of the quadrant cuts the other star also, you have guessed the time exactly; but if it does not, turn the globe slowly backwards or forwards, until the quadrant (kept upon either star) cuts them both through their centers: and then, the index will point out the exact time of the night; the degree of the horizon, cut by the quadrant, will be the true azimuth of both these stars from the south; and the stars themselves will cut their true altitudes in the quadrant. At which moment, if a common azimuth compass be so set upon a floor or level pavement, that these stars in the heaven may have the same bearing upon it (allowing for the variation of the needle) as the quadrant of altitude has in the wooden horizon of the globe, a thread extended over the north and south points of that compass, will

will be directly in the plane of the meridian: and if a line be drawn upon the floor or pavement, along the course of the thread, and an upright wire be placed in the southmost end of the line, the shadow of the wire will fall upon that line, when the sun is on the meridian, and shines upon the pavement.

PROBLEM IX.

To find the place of the moon, or of any planet; and thereby to shew the time of its rising, southing, and setting.

Seek in *Parker*'s or *Weaver*'s Ephemeris the * geocentric place of the moon or planet in the ecliptic, for the given day of the month; and, according to its longitude and latitude, as shewn by the Ephemeris, mark the same with a chalk upon the globe. Then, having rectified the globe, turn it round its axis westward; and as the said mark comes to the eastern side of the horizon, to the brasen meridian, and to the western side of the horizon, the index will shew at what time the planet rises, comes to the meridian, and sets, in the same manner as it would do for a fixed star.

PROBLEM X.

To explain the phenomena of the harvest-moon.

In order to do this, we must premise the following things. 1. That as the sun goes only

* The place of the moon or planet, as seen from the earth, is called its geocentric place.

nce a year round the ecliptic, he can be but nce a year in any particular point of it: and hat his motion is almoſt a degree every 24 ours, at a mean rate. 2. That as the moon oes round the ecliptic once in 27 days and 8 ours, ſhe advances $13\frac{1}{3}$ degrees in it, every day t a mean rate. 3. That as the ſun goes hrough part of the ecliptic in the time the oon goes round it, the moon cannot at any time e either in conjunction with the ſun, or oppoſite o him, in that part of the ecliptic where ſhe was the laſt time before; but muſt travel as uch forwarder, as the ſun has advanced in the id time; which being $29\frac{1}{2}$ days, makes almoſt whole ſign. Therefore, 4. The moon can be ut once a year oppoſite to the ſun, in any articular part of the ecliptic. 5. That the oon is never full but when ſhe is oppoſite to e ſun, becauſe at no other time can we ſee all at half of her, which the ſun enlightens. 6. That hen any point of the ecliptic riſes, the oppoſite oint ſets. Therefore, when the moon is oppo-e to the ſun, ſhe muſt riſe at * ſun-ſet. 7. That e different ſigns of the ecliptic riſe at very dif-erent angles or degrees of obliquity with the orizon, eſpecially in conſiderable latitudes; and at the ſmaller this angle is, the greater is the ortion of the ecliptic that riſes in any ſmall part f time; and *vice verſâ*. 8. That, in northern titudes, no part of the ecliptic riſes at ſo ſmall n angle with the horizon, as *Piſces* and *Aries* do; herefore, a greater portion of the ecliptic riſes in

* This is not always ſtrictly true, becauſe the moon does t keep in the ecliptic, but croſſes it twice every month. owever, the difference need not be regarded in a general xplanation.

X one

one hour, about these signs, than about any the rest. 9. That the moon can never be f in *Pisces* and *Aries* but in our autumnal month for at no other time of the year is the sun in t opposite signs *Virgo* and *Libra*.

These things premised, take $13\frac{1}{6}$ degrees the ecliptic in your compasses, and beginning *Pisces*, carry that extent all round the eclipti marking the places with a chalk, where t points of the compasses successively fall. you will have the moon's daily motion mark out for one compleat revolution in the eclip (according to § 2 of the last paragraph.)

Rectify the globe for any considerable northe latitude, (as suppose that of London) and the turning the globe round its axis, observe ho much of the hour-circle the index has gone ove at the rising of each particular mark on t ecliptic; and you will find that seven of t marks (which take in as much of the ecliptic the moon goes through in a week) will all ri successively about *Pisces* and *Aries*, in the tim that the index goes over two hours. Therefor whilst the moon is in *Pisces* and *Aries*, she will n differ in general above two hours in her risin for a whole week. But if you take notice o the marks on the opposite signs, *Virgo* and *Libr* you will find that seven of them take nine hou to rise; which shews, that when the moon is i these two signs, she differs nine hours in he rising within the compass of a week. And s much later as every mark is of rising than th one that rose next before it, so much later wi the moon be of rising any day, than she was o the day before, in the corresponding part of th heaven. The marks about *Cancer* and *Capricor*

ris

rise at a mean difference of time between those about *Aries* and *Libra*.

Now, although the moon is in *Pisces* and *Aries* every month, and therefore must rise in those signs within the space of two hours later for a whole week, or only about 17 minutes later every day than she did on the former; yet she is never full in these signs, but in our autumnal months, *August* and *September*, when the sun is in *Virgo* and *Libra*. Therefore, no full moon in the year will continue to rise so near the time of sun-set for a week or so, as these two full moons do, which fall in the time of harvest.

In the winter months, the moon is in *Pisces* and *Aries* about her first quarter; and as these signs rise about noon in winter, the moon's rising in them passes un-observed. In the spring months, the moon changes in these signs, and consequently rises at the same time with the sun; so that it is impossible to see her at that time. In the summer months she is in these signs about her third quarter, and rises not until mid-night, when her rising is but very little taken notice of; especially as she is on the decrease. But in the harvest months she is at the full, when in these signs, and being opposite to the sun, she rises when the sun sets (or soon after) and shines all the night.

In southern latitudes, *Virgo* and *Libra* rise at as small angles with the horizon, as *Pisces* and *Aries* do in the northern; and as our spring is at the time of their harvest, it is plain their harvest full moons must be in *Virgo* and *Libra*; and will therefore rise with as little difference of time, as ours do in *Pisces* and *Aries*.

For a fuller account of this matter, I
refer the reader to my Astronomy, in wh
described at large.

PROBLEM XI.

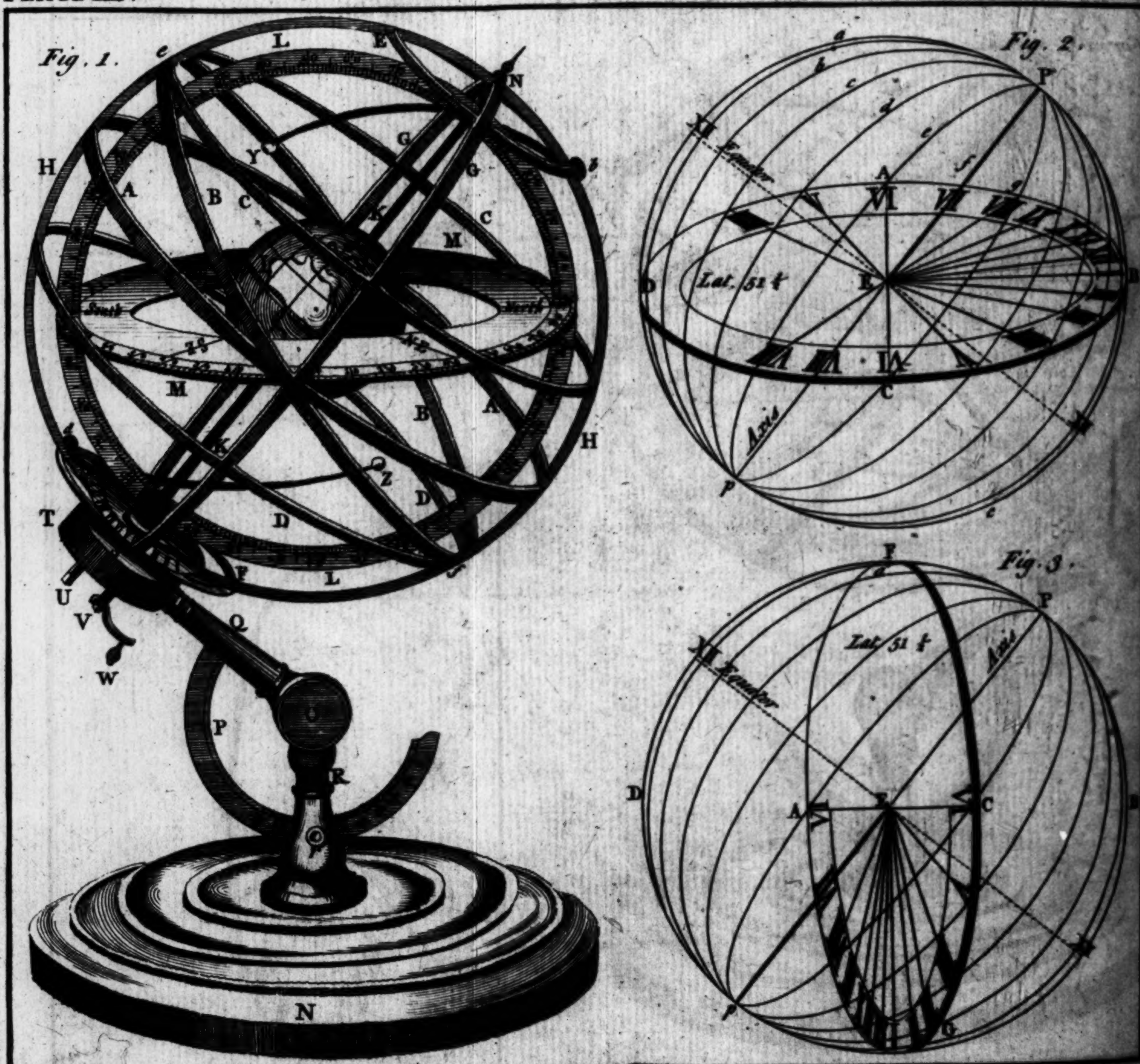
To explain the equation of time, or difference
between well-regulated clocks and true sun-d

The earth's motion on its axis being per
equable, and thereby causing an app
equable motion of the starry heaven round
same axis, produced to the poles of the hea
it is plain that equal portions of the cele
equator pass over the meridian in equal parts
time, because the axis of the world is perpen
cular to the plane of the equator. And there
fore, if the sun kept his annual course in th
celestial equator, he would always revolve from
the meridian to the meridian again in 24 hour
exactly, as shewn by a well-regulated clock.

But as the sun moves in the ecliptic, which
oblique both to the plane of the equator and ax
of the world, he cannot always revolve from th
meridian to the meridian again in 24 equa
hours; but sometimes a little sooner, and
other times a little later, because equal portion
of the ecliptic pass over the meridian in unequa
parts of time, on account of its obliquity. An
this difference is the same in all latitudes.

To shew this by a globe, make chalk-ma
all around the equator and ecliptic, at equ
distances from one another (suppose 10 degree
beginning at *Aries* or at *Libra*, where these tw
circles intersect each other. Then turn th
globe

PLATE XX.



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globe round its axis, and you will ſee that all the marks in the firſt quadrant of the ecliptic, or from the beginning of *Aries* to the beginning of *Cancer*, come ſooner to the braſen meridian than their correſponding marks do on the equator: thoſe in the ſecond quadrant, or from the beginning of *Cancer* to the beginning of *Libra*, come later: thoſe in the third quadrant, from *Libra* to *Capricorn*, ſooner; and thoſe in the fourth, from *Capricorn* to *Aries*, later. But thoſe at the beginning of each quadrant come to the meridian at the ſame time with their correſponding marks on the equator.

Therefore, whilſt the ſun is in the firſt and third quadrants of the ecliptic, he comes ſooner to the meridian every day than he would do if he kept in the equator; and conſequently he is faſter than a well-regulated clock, which always keeps equable or equatorial time: and whilſt he is in the ſecond and fourth quadrants, he comes later to the meridian every day than he would do if he kept in the equator; and is therefore ſlower than the clock. But at the beginning of each quadrant, the ſun and clock are equal.

And thus, if the ſun moved equably in the ecliptic, he would be equal with the clock on four days of the year, which would have equal intervals of time between them. But as he moves faſter at ſometimes than at others (being eight days longer in the northern half of the ecliptic than in the ſouthern) this will cauſe a ſecond inequality; which combined with the former, ariſing from the obliquity of the ecliptic to the equator, makes up that difference, which is ſhewn by the common equation tables to be between good clocks and true ſun-dials.

The description and use of the armillary sphere.

Plate XX. Fig. 1.

Whoever has seen a common *armillary sphere*, and understands how to use it, must be sensible that the machine here referred to, is of a very different, and much more advantageous construction. And whoever has seen the curious glass sphere invented by Dr. LONG, or the figure of it in his Astronomy, must know that the furniture of the terrestrial globe in this machine, the form of the pedestal, and the manner of turning either the earthly globe, or the circles which surround it, are all copied from the Doctor's glass sphere; and that the only difference is, a parcel of rings instead of a glass celestial globe; and all the additions are a moon within the sphere, and a semicircle upon the pedestal.

The armillary sphere.

The exterior parts of this machine are a compages of brass rings, which represent the principal circles of the heaven, viz. 1. The equinoctial *A A*, which is divided into 360 degrees (beginning at its intersection with the ecliptic in *Aries*) for shewing the sun's right ascension in degrees; and also into 24 hours, for shewing his right ascension in time. 2. The ecliptic *B B*, which is divided into 12 signs, and each sign into 30 degrees, and also into the months and days of the year; in such a manner, that the degree or point of the ecliptic in which the sun is, on any given day, stands over that day in the circle of months. 3. The tropic of *Cancer C C*, touching the ecliptic at the beginning of *Cancer* in *e*, and the tropic of *Capricorn D D*, touching the ecliptic at the beginning of *Capricorn* in *f*; each 23½ degrees from

from the equinoctial circle. 4. The arctic circle *E*, and the antarctic circle *F*, each $23\frac{1}{2}$ degrees from its respective pole at *N* and *S*. 5. The equinoctial colure *G G*, passing through the north and south poles of the heaven at *N* and *S*, and through the equinoctial points *Aries*, and *Libra*, in the ecliptic. 6. The solstitial colure *HH*, passing through the poles of the heaven, and through the solstitial points *Cancer* and *Capricorn*, in the ecliptic. Each quarter of the former of these colures is divided into 90 degrees, from the equinoctial to the poles of the world, for shewing the declination of the sun, moon, and stars; and each quarter of the latter, from the ecliptic at *e* and *f*, to its poles *b* and *d*, for shewing the latitudes of the stars.

In the north pole of the ecliptic is a nut *b*, to which is fixed one end of a quadrantal wire, and to the other end a small sun *Y*, which is carried round the ecliptic *B B*, by turning the nut: and in the south pole of the ecliptic is a pin at *d*, on which is another quadrantal wire, with a small moon *Z* upon it, which may be moved round by hand: but there is a particular contrivance for causing the moon to move in an orbit which crosses the ecliptic at an angle of $5\frac{1}{3}$ degrees, in two opposite points called the ***moon's nodes***; and also for shifting these points backward in the ecliptic, as the ***moon's nodes*** shift in the heaven.

Within these circular rings is a small terrestrial globe *I*, fixt on an axis *KK*, which extends from the north and south poles of the globe at *n* and *s*, to those of the celestial sphere at *N* and *S*. On this axis is fixt the flat celestial meridian *L L*, which may be set directly over the meridian of any place on the globe, and then turned round with the globe, so as to keep over the same

meridian upon it. This flat meridian is graduated the ſame way as the braſs meridian of a common globe, and its uſe is much the ſame. To this globe is fitted the moveable horizon *MM*, ſo as to turn upon two ſtrong wires proceeding from its eaſt and weſt points to the globe, and entering the globe at oppoſite points of its equator, which is a moveable braſs ring let into the globe in a groove all around its equator. The globe may be turned by hand within this ring, ſo as to place any given meridian upon it, directly under the celeſtial meridian *LL*. The horizon is divided into 360 degrees all around its outermoſt edge, within which are the points of the compaſs, for ſhewing the amplitude of the ſun and moon, both in degrees and points. The celeſtial meridian *LL* paſſes through two notches in the north and ſouth points of the horizon, as in a common globe: but here, if the globe be turned round, the horizon and meridian turn with it. At the ſouth pole of the ſphere is a circle of 24 hours, fixt to the rings, and on the axis is an index which goes round that circle, if the globe be turned round its axis.

The whole fabrick is ſupported on a pedeſtal *N*, and may be elevated or depreſſed upon the joint *O*, to any number of degrees from 0 to 90, by means of the arc *P*, which is fixed in the ſtrong braſs arm *Q*, and ſlides in the upright piece *R*, in which is a ſcrew at *r*, to fix it at any proper elevation.

In the box *T* are two wheels (as in Dr. *Long*'s ſphere) and two pinions, whoſe axes come out at *V* and *U*; either of which may be turned by the ſmall winch *W*. When the winch is put upon the axis *V*, and turned backward, the ter-

reſtrial

reſtrial globe, with its horizon and celeſtial meridian, keep at reſt; and the whole ſphere of circles turns round from eaſt, by ſouth, to weſt, carrying the ſun *Y*, and moon *Z*, round the ſame way, and cauſing them to riſe above and ſet below the horizon. But when the winch is put upon the axis *U*, and turned forward, the ſphere with the ſun and moon keep at reſt; and the earth, with its horizon and meridian, turn round from weſt, by ſouth, to eaſt; and bring the ſame points of the horizon to the ſun and moon, to which theſe bodies came when the earth kept at reſt, and they were carried round it; ſhewing that they riſe and ſet in the ſame points of the horizon, and at the ſame times in the hour-circle, whether the motion be in the earth or in the heaven. If the earthly globe be turned, the hour-index goes round its hour-circle; but if the ſphere be turned, the hour-circle goes round below the index.

And ſo, by this conſtruction, the machine is equally fitted to ſhew either the real motion of the earth, or the apparent motion of the heaven.

To rectify the ſphere for uſe, firſt ſlacken the ſcrew *r* in the upright ſtem *R*, and taking hold of the arm *Q*, move it up or down until the given degree of latitude for any place be at the ſide of the ſtem *R*; and then the axis of the ſphere will be properly elevated, ſo as to ſtand parallel to the axis of the world, if the machine be ſet north and ſouth by a ſmall compaſs: this done, count the latitude from the north pole, upon the celeſtial meridian *L L*, down towards the north notch of the horizon, and ſet the horizon to that latitude; then, turn the nut *b* until the ſun *Y* comes to the given day of the year in the

the ecliptic, and the ſun will be at its proper place for that day: find the place of the moon's aſcending node, and alſo the place of the moon, by an Ephemeris, and ſet them right accordingly: laſtly, turn the winch *W*, until either the ſun comes to the meridian *L L*, or until the meridian comes to the ſun (according as you want the ſphere or earth to move) and ſet the hour-index to the XII, marked noon, and the whole machine will be rectified.——Then turn the winch, and obſerve when the ſun or moon riſe and ſet in the horizon, and the hour-index will ſhew the times thereof for the given day.

As thoſe who underſtand the uſe of the globes will be at no loſs to work many other problems by this ſphere, it is needleſs to enlarge any farther upon it.

LECT. X.

The principles and art of dialing.

Prelimi-naries.

A Dial is a plane, upon which lines are deſcribed in ſuch a manner, that the ſhadow of a wire, or of the upper edge of a plate ſtile, erected perpendicularly on the plane of the dial, may ſhew the true time of the day.

The edge of the plate by which the time of the day is found, is called the ſtile of the dial, which muſt be parallel to the earth's axis; and the line on which the ſaid plate is erected, is called the ſubſtile.

The angle included between the ſubſtile and ſtile, is called the elevation, or height of the ſtile.

Thoſe dials whoſe planes are parallel to the plane of the horizon, are called horizontal dials; and

and thofe dials whofe planes are perpendicular to the plane of the horizon, are called vertical, or erect dials.

Thofe erect dials, whofe planes directly front the north or fouth, are called direct north or fouth dials; and all other erect dials are called decliners, becaufe their planes are turned away from the north or fouth.

Thofe dials whofe planes are neither parallel nor perpendicular to the plane of the horizon, are called inclining, or reclining dials, according as their planes make acute or obtufe angles with the horizon; and if their planes are alfo turned afide from facing the fouth or north, they are called declining-inclining, or declining-reclining dials.

The interfection of the plane of the dial, with that of the meridian, paffing through the ftile, is called the meridian of the dial, or the hour-line of XII.

Thofe meridians, whofe planes pafs through the ftile, and make angles of 15, 30, 45, 60, 75, and 90 degrees with the meridian of the place (which marks the hour-line of XII) are called hour circles; and their interfections with the plane of the dial, are called hour-lines.

In all declining dials, the fubftile makes an angle with the hour-line of XII; and this angle is called the diftance of the fubftile from the meridian.

The declining plane's difference of longitude, is the angle formed at the interfection of the ftile and plane of the dial, by two meridians; one of which paffes through the hour-line of XII, and the other through the fubftile.

This

This much being premised concerning dials in general, we shall now proceed to explain the different methods of their construction.

Plate XX. Fig. 2.

The universal principle on which *dialing* depends.

If the whole earth *a P c p* were transparent, and hollow, like a sphere of glass, and had its equator divided into 24 equal parts by so many meridian semicircles, *a*, *b*, *c*, *d*, *e*, *f*, *g*, &c. one of which is the geographical meridian of any given place, as London (which is supposed to be at the point *a*;) and if the hours of XII were marked at the equator, both upon that meridian and the opposite one, and all the rest of the hours in order on the rest of the meridians, those meridians would be the hour-circles of London: then, if the sphere had an opake axis, as *P E p*, terminating in the poles *P* and *p*, the shadow of the axis would fall upon every particular meridian and hour, when the sun came to the plane of the opposite meridian, and would consequently shew the time at London, and at all other places on the meridian of London.

Horizontal dial.

If this sphere was cut through the middle by a solid plane *A B C D*, in the rational horizon of London, one half of the axis *E P* would be above the plane, and the other half below it; and if straight lines were drawn from the center of the plane, to those points where its circumference is cut by the hour-circles of the sphere, those lines would be the hour-lines of a horizontal dial for London: for the shadow of the axis would fall upon each particular hour-line of the dial, when it fell upon the like hour-circle of the sphere.

Fig. 3.

If the plane which cuts the sphere be upright, as *A F C G*, touching the given place (London) at *F*, and directly facing the meridian of London,

don, it will then become the plane of an erect direct south dial: and if right lines be drawn from its center *E*, to those points of its circumference where the hour-circles of the sphere cut it, these will be the hour-lines of a vertical or direct south dial for London, to which the hours are to be set as in the figure (contrary to those on a horizontal dial) and the lower half *Ep* of the axis will cast a shadow on the hour of the day in this dial, at the same time that it would fall upon the like hour-circle of the sphere, if the dial-plane was not in the way.

Vertical dial.

If the plane (still facing the meridian) be made to incline, or recline, by any given number of degrees, the hour-circles of the sphere will still cut the edge of the plane in those points to which the hour-lines must be drawn straight from the center; and the axis of the sphere will cast a shadow on these lines at the respective hours. The like will still hold, if the plane be made to decline by any given number of degrees from the meridian, towards the east or west: provided the declination be less than 90 degrees, or the reclination be less than the co-latitude of the place: and the axis of the sphere will be a gnomon, or stile, for the dial. But it cannot be a gnomon, when the declination is quite 90 degrees, nor when the reclination is equal to the co-latitude; because in these two cases, the axis has no elevation above the plane of the dial.

Inclining and reclining dials.

Declining dials.

And thus it appears, that the plane of every dial represents the plane of some great circle upon the earth; and the gnomon the earth's axis, whether it be a small wire, as in the above figures, or the edge of a thin plate, as in the common horizontal dials.

The

The whole earth, as to its bulk, is but a point, if compared to its diſtance from the ſun: and therefore, if a ſmall ſphere of glaſs be placed upon any part of the earth's ſurface, ſo that its axis be parallel to the axis of the earth, and the ſphere have ſuch lines upon it, and ſuch planes within it, as above deſcribed; it will ſhew the hours of the day as truly as if it were placed at the earth's center, and the ſhell of the earth were as tranſparent as glaſs.

But becauſe it is impoſſible to have a hollow ſphere of glaſs perfectly true, blown round a

Fig. 2, 3. ſolid plane; or if it was, we could not get at the plane within the glaſs to ſet it in any given poſition; we make uſe of a wire-ſphere to explain the principles of dialing, by joining 24 ſemicircles together at the poles, and putting a thin flat plate of braſs within it.

Dialing by the common *terreſtrial globe.*

A common globe, of 12 inches diameter, has generally 24 meridian ſemicircles drawn upon it. If ſuch a globe be elevated to the latitude of any given place, and turned about until any one of theſe meridians cuts the horizon in the north point, where the hour of XII is ſuppoſed to be marked, the reſt of the meridians will cut the horizon at the reſpective diſtances of all the other hours from XII. Then, if theſe points of diſtance be marked on the horizon, and the globe be taken out of the horizon, and a flat board or plate be put into its place, even with the ſurface of the horizon; and if ſtraight lines be drawn from the center of the board, to thoſe points of diſtance on the horizon which were cut by the 24 meridian ſemicircles, theſe lines will be the hour-lines of a horizontal dial for that latitude, the edge of whoſe gnomon muſt be in the very ſame ſituation that the axis of the

3 glob

globe was, before it was taken out of the horizon: that is, the gnomon muſt make an angle with the plane of the dial, equal to the latitude of the place for which the dial is made.

If the pole of the globe be elevated to the * co-latitude of the given place, and any meridian be brought to the north point of the horizon, the reſt of the meridians will cut the horizon in the reſpective diſtances of all the hours from XII, for a direct ſouth dial, whoſe gnomon muſt make an angle with the plane of the dial, equal to the co-latitude of the place; and the hours muſt be ſet the contrary way on this dial, to what they are on the horizontal.

But if your globe have more than 24 meridian ſemicircles upon it, you muſt take the following method for making *horizontal* and *ſouth dials*.

To conſtruct a *horizontal dial.*

Elevate the pole to the latitude of your place, and turn the globe until any particular meridian (ſuppoſe the firſt) comes to the north point of the horizon, and the oppoſite meridian will cut the horizon in the ſouth. Then, ſet the hour-index to the uppermoſt XII on its circle; which done, turn the globe weſtward until 15 degrees of the equator paſs under the braſen meridian, and then the hour-index will be at I (for the ſun moves 15 degrees every hour) and the firſt meridian will cut the horizon in the number of degrees from the north point, that I is diſtant from XII. Turn on, until other 15 degrees of the equator paſs under the braſen meridian, and the hour-index will then be at II, and the firſt meridian

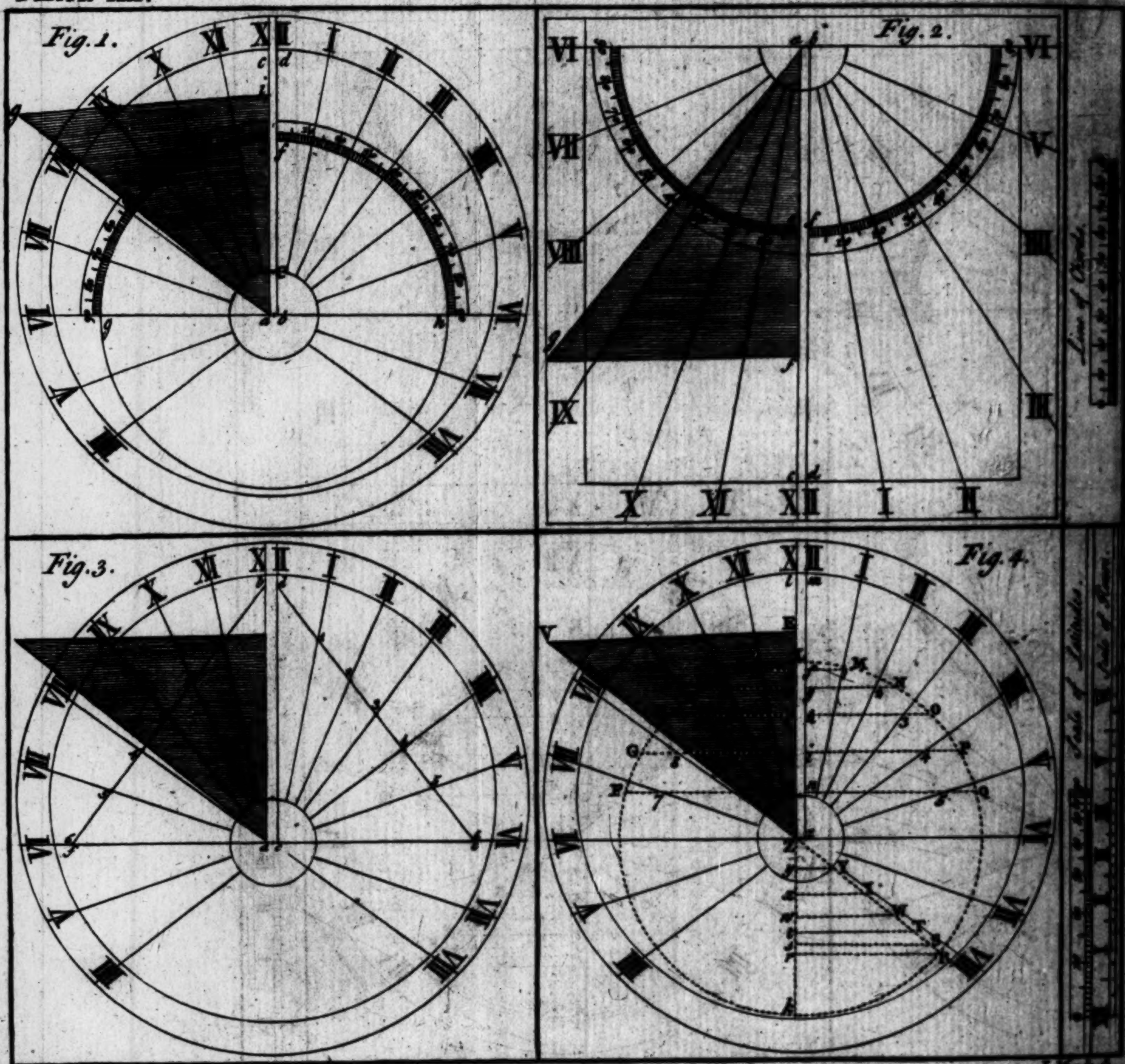
* If the latitude be ſubtracted from 90 degrees, the remainder is called the co-latitude, or complement of the latitude.

ridian will cut the horizon in the number of degrees that II is distant from XII: and so, by making 15 degrees of the equator pass under the brasen meridian for every hour, the first meridian of the globe will cut the horizon in the distances of all the hours from XII to VI, which is just 90 degrees; and then you need go no farther, for the distances of XI, X, IX, VIII, VII, and VI, in the forenoon, are the same from XII, as the distances of I, II, III, IV, V, and VI, in the afternoon: and these hour-lines continued through the center, will give the opposite hour-lines on the other half of the dial: but no more of these lines need be drawn, than what answer to the sun's continuance above the horizon of your place on the longest day, which may be easily found by the 26th problem of the foregoing lecture.

Thus, to make a horizontal dial for the latitude of London, which is $51\frac{1}{2}$ degrees north, elevate the north pole of the globe $51\frac{1}{2}$ degrees above the north point of the horizon, and then turn the globe, until the first meridian (which is that of London on the English terrestrial globe) cuts the north point of the horizon, and set the hour-index to XII at noon.

Then, turning the globe westward until the index points successively to I, II, III, IIII, V, and VI, in the afternoon; or until 15, 30, 45, 60, 75, and 90 degrees of the equator pass under the brasen meridian, you will find that the first meridian of the globe cuts the horizon in the following numbers of degrees from the north towards the east, viz. $11\frac{2}{3}$, $24\frac{1}{4}$, $38\frac{1}{11}$, 53[illegible], $71\frac{1}{11}$, and 90; which are the respective distances of the above hours from XII upon the plane of the horizon.

PLATE XXI.



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To transfer these, and the rest of the hours, to a horizontal plane, draw the parallel right lines *a c* and *b d* upon that plane, as far from each other as is equal to the intended thickness of the gnomon or stile of the dial, and the space included between them will be the meridian or twelve o'clock line on the dial. Cross this meridian at right angles with the six o'clock line *g h*, and setting one foot of your compasses in the intersection *a*, as a center, describe the quadrant *g e* with any convenient radius or opening of the compasses: then, setting one foot in the intersection *b*, as a center, with the same radius describe the quadrant *f h*, and divide each quadrant into 90 equal parts or degrees, as in the figure. Plate XXI. Fig. 1.

Because the hour-lines are less distant from each other about noon, than in any other part of the dial, it is best to have the centers of these quadrants at a little distance from the center of the dial-plane, on the side opposite to XII, in order to enlarge the hour-distances thereabouts, under the same angles on the plane. Thus, the center of the plane is at *C*, but the centers of the quadrants at *a* and *b*.

Lay a ruler over the point *b* (and keeping it there for the center of all the afternoon hours in the quadrant *f b*) draw the hour-line of I, through $11\frac{2}{3}$ degrees in the quadrant; the hour-line of II, through $24\frac{1}{4}$ degrees; of III, through $38\frac{1}{12}$ degrees; IIII, through $53\frac{1}{2}$, and V through $71\frac{1}{12}$: and because the sun rises about four in the morning, on the longest days at London, continue the hour-lines of IIII and V in the afternoon, through the center *b* to the opposite side of the dial.—This done, lay the ruler to the center *a*, of the quadrant *e g*, and through the

like divisions or degrees of that quadrant, viz. $11\frac{2}{3}$, $24\frac{1}{4}$, $38\frac{1}{12}$, $53\frac{1}{2}$, and $71\frac{1}{12}$, draw the fore-noon hour-lines of XI, X, IX, VIII, and VII and because the sun sets not before eight in the evening on the longest days, continue the hour-lines of VII and VIII in the forenoon, through the center *a*, to VII and VIII in the afternoon; and all the hour-lines will be finished on this dial to which the hours may be set, as in the figure.

Lastly, through $51\frac{1}{2}$ degrees of either quadrant, and from its center, draw the right line *ag* for the hypothenuse or axis of the gnomon *agi* and from *g*, let fall the perpendicular *gi*, upon the meridian line *ai*, and there will be a triangle made, whose sides are *ag*, *gi*, and *ia*. If a plate similar to this triangle be made as thick as the distance between the lines *ac* and *bd*, and set upright between them, touching at *a* and *b*, its hypothenuse *ag* will be parallel to the axis of the world, when the dial is truly set; and will cast a shadow on the hour of the day.

N. B. The trouble of dividing the two quadrants, may be saved, if you have a scale with a line of chords upon it, such as that on the right hand of the plate: for if you extend the compasses from 0 to 60 degrees of the line of chords and with that extent, as a radius, describe the two quadrants upon their respective centers, the above distances may be taken with the compasses upon the line, and set off upon the quadrants.

Fig. 2. To construct an *erect south dial.*

To make an erect direct south dial. Elevate the pole to the co-latitude of your place, and proceed in all respects as above taught for the horizontal dial, from VI in the morning to VI in the afternoon, only the hours must be reversed, as in the figure; and the hypothenuse *ag*, of the gnomo[n]

gnomon *agf*, must make an angle with the dial-plane equal to the co-latitude of the place. As the sun can shine no longer on this dial, than from six in the morning until six in the evening, there is no occasion for having any more than twelve hours upon it.

To make an erect dial, declining from the south towards the east or west. Elevate the pole to the latitude of your place, and screw the quadrant of altitude to the zenith. Then, if your dial declines towards the east (which we shall suppose it to do at present) count in the horizon the degrees of declination, from the east point towards the north, and bring the lower end of the quadrant to that degree of declination at which the reckoning ends. This done, bring any particular meridian of your globe (as suppose the first meridian) directly under the graduated edge of the upper part of the brasen meridian, and set the hour-index to XII at noon. Then, keeping the quadrant of altitude at the degree of declination in the horizon, turn the globe eastward on its axis, and observe the degrees cut by the first meridian in the quadrant of altitude (counted from the zenith) as the hour-index comes to XI, X, IX, &c. in the forenoon, or as 15, 30, 45, &c. degrees of the equator pass under the brasen meridian at these hours respectively; and the degrees then cut in the quadrant by the first meridian, are the respective distances of the forenoon hours from XII on the plane of the dial.—Then, for the afternoon hours, turn the quadrant of altitude round the zenith until it comes to the degree in the horizon opposite to that where it was placed before; namely, as far from the west point of the horizon towards the south, as it was set at first from the east point towards the north; and turn the globe westward on

To construct an *erect declining dial.*

on its axis, until the firſt meridian comes to the braſen meridian again, and the hour-index to XII: then, continue to turn the globe weſtward, and as the index points to the afternoon hours I, II, III, &c. or as 15, 30, 45, &c. degrees of the equator paſs under the braſen meridian, the firſt meridian will cut the quadrant of altitude in the reſpective number of degrees from the zenith, that each of theſe hours is from XII on the dial.—And note, that when the firſt meridian goes off the quadrant at the horizon, in the forenoon, the hour-index ſhews the time when the ſun will come upon this dial: and when it goes off the quadrant in the afternoon, the index will point to the time when the ſun goes off the dial.

Having thus found all the hour-diſtances from XII, lay them down upon your dial-plate, either by dividing a ſemicircle into two quadrants of 90 degrees each (beginning at the hour-line of XII) or by the line of chords, as above directed.

In all declining dials, the line on which the ſtile or gnomon ſtands (commonly called the *ſubſtile-line)* makes an angle with the twelve o'clock line, and falls among the forenoon hour-lines, if the dial declines towards the eaſt; and among the afternoon hour-lines, when the dial declines towards the weſt; that is, to the left hand from the twelve o'clock line in the former caſe, and to the right hand from it in the latter.

To find the diſtance of the ſubſtile from the twelve o'clock line; if your dial declines from the ſouth toward the eaſt, count the degrees of that declination in the horizon from the eaſt point toward the north, and bring the lower end of the quadrant of altitude to that degree of declination

declination where the reckoning ends: then, turn the globe until the first meridian cuts the horizon in the like number of degrees, counted from the south point toward the east; and the quadrant and first meridian will then cross one another at right angles, and the number of degrees of the quadrant, which are intercepted between the first meridian and the zenith, is equal to the distance of the substile line from the twelve o'clock line; and the number of degrees of the first meridian, which are intercepted between the quadrant and the north pole, is equal to the elevation of the stile above the plane of the dial.

If the dial declines westward from the south, count that declination from the east point of the horizon towards the south, and bring the quadrant of altitude to the degree in the horizon at which the reckoning ends; both for finding the forenoon hours, and the distance of the substile from the meridian: and for the afternoon hours, bring the quadrant to the opposite degree in the horizon, namely, as far from the west towards the north, and then proceed in all respects as above.

Thus, we have finished our declining dial; and in so doing, we made four dials, viz.

1. A north dial, declining eastward by the same number of degrees. 2. A north dial, declining the same number west. 3. A south dial, declining east. And, 4, a south dial declining west. Only, placing the proper number of hours, and the stile or gnomon respectively, upon each plane. For (as above-mentioned) in the south-west plane, the substilar-line falls among the afternoon hours; and in the south-east, of the same declination among the forenoon

hours, at equal diſtances from XII. And ſo all the morning hours on the weſt decliner will be like the afternoon hours on the eaſt decliner; the ſouth-eaſt decliner will produce the north-weſt decliner; and the ſouth-weſt decliner, the north-eaſt decliner, by only extending the hour-lines, ſtile and ſubſtile, quite through the center: the axis of the ſtile (or edge that caſts the ſhadow on the hour of the day) being in all dials whatever parallel to the axis of the world, and conſequently pointing towards the north pole of the heaven in north latitudes, and towards the ſouth pole, in ſouth latitudes. *See more of this in the following lecture.*

An eaſy method for conſtructing of *dials*.

But becauſe every one who would like to make a dial, may perhaps not be provided with a globe to aſſiſt him, and may probably not underſtand the method of doing it by logarithmic calculation; we ſhall ſhew how to perform it by the plain dialing lines, or ſcale of latitudes and hours; ſuch as thoſe on the right hand of Fig. 4. in Plate XXI, or at the top of Plate XXII, and which may be had on ſcales commonly ſold by the mathematical inſtrument makers.

This is the eaſieſt of all mechanical methods, and by much the beſt, when the lines are truly divided: not only the half hours and quarters may be laid down by all of them, but every fifth minute by moſt, and every ſingle minute by thoſe where the line of hours is a foot in length.

Fig. 3.

Having drawn your double meridian line *a b*, *c d*, on the plane intended for a horizontal dial, and croſſed it at right angles by the ſix o'clock line *f e* (as in Fig. 1.) take the latitude of your place with the compaſſes, in the ſcale of latitudes, and ſet that extent from *c* to *e*, and from *a* to *f*, on the ſix o'clock line: then, taking the whole ſix

hours

hours between the points of the compasses in the scale of hours, with that extent set one foot in the point *c*, and let the other foot fall where it will upon the meridian line *cd*, as at *d*. Do the same from *f* to *b*, and draw the right lines *e d* and *f b*, each of which will be equal in length to the whole scale of hours. This done, setting one foot of the compasses in the beginning of the scale at XII, and extending the other to each hour on the scale, lay off these extents from *d* to *e* for the afternoon hours, and from *b* to *f* for those of the forenoon: this will divide the lines *d e* and *b f* in the same manner as the hour-scale is divided, at 1, 2, 3, 4, 5 and 6; on which the quarters may also be laid down, if required. Then, laying a ruler on the point *c*, draw the first five hours in the afternoon, from that point, through the dots at the numeral figures 1, 2, 3, 4, 5, on the line *d e*; and continue the lines of IIII and V through the center *c* to the other side of the dial, for the like hours of the morning; which done, lay the ruler on the point *a*, and draw the last five hours in the forenoon through the dots 5, 4, 3, 2, 1, on the line *f b*; continuing the hour-lines of VII and VIII through the center *a* to the other side of the dial, for the like hours of the evening; and set the hours to their respective lines, as in the figure. Lastly, make the gnomon the same way as taught above for the horizontal dial, and the whole will be finished.

To make an erect south dial, take the co-latitude of your place from the scale of latitudes, and then proceed in all respects for the hour-lines, as in the horizontal dial; only reversing the hours, as in Fig. 2; and making the angle of the stile's height equal to the co-latitude.

I have drawn out a ſet of dialing lines upon the top of the 22d Plate, large enough for making a dial of nine inches diameter, or more inches if required; and have drawn them tolerably exact for common practice, to every quarter of an hour. This ſcale may be cut off from the plate, and paſted on wood, or upon the inſide of one of the boards of this book; and then it will be ſomewhat more exact than it is on the plate, for being rightly divided upon the copper-plate, and printed off on wet paper, it ſhrinks as the paper dries: but when it is wetted again, it ſtretches to the ſame ſize as when newly printed, and if paſted on while wet, it will remain of that ſize afterward.

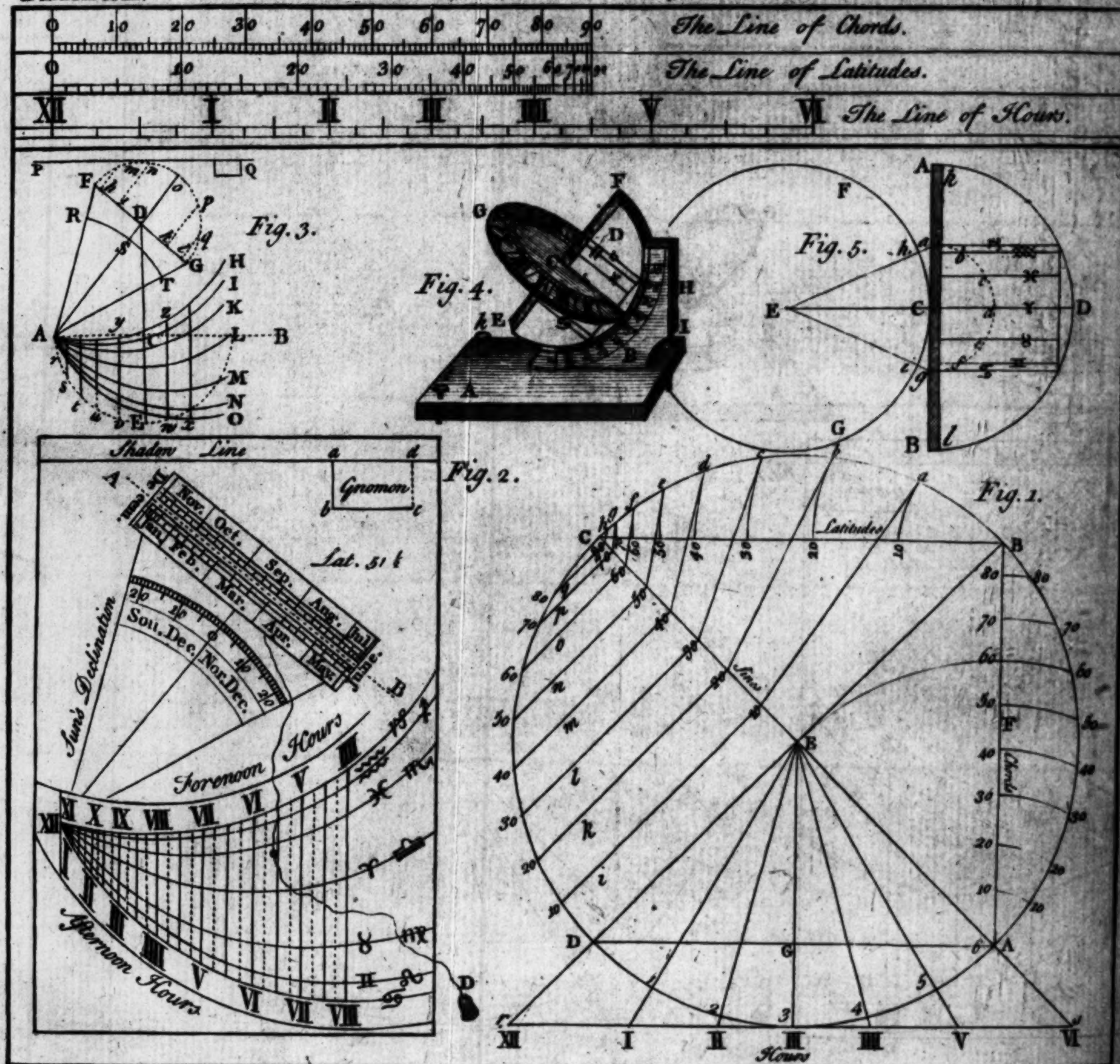
But leſt the young dialiſt ſhould have neither globe nor wooden ſcale, and ſhould tear or otherwiſe ſpoil the paper one in paſting, we ſhall now ſhew him how he may make a dial without any of theſe helps. Only, if he has not a line of chords, he muſt divide a quadrant into 90 equal parts or degrees for taking the proper angle of the ſtile's elevation, which is eaſily done.

Fig. 4. With any opening of the compaſſes, as ZL, deſcribe the two ſemicircles LFk and LQk, upon the centers Z and z, where the ſix o'clock line croſſes the double meridian line, and divide each ſemicircle into 12 equal parts, beginning at L (though, ſtrictly ſpeaking, only the quadrants from L to the ſix o'clock line need be divided); then connect the diviſions which are equidiſtant from L, by the parallel lines KM, IN, HO, GP, and FQ. Draw VZ for the hypothenuſe of the ſtile, making the angle VZE equal to the latitude of your place; and continue the line VZ to R. Draw the line Rr parallel to the ſix o'clock line, and ſet off the diſtance aK from Z to f,

Horizontal dial.

the

PLATE XXII.



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J. Mynde sc.

the distance *b I* from *Z* to *X*, *c H* from *Z* to *W*, *d G* from *Z* to *T*, and *e F* from *Z* to *S*. Then draw the lines *S s*, *T t*, *W w*, *X x*, and *Y y*, each parallel to *R r*. Set off the distance *y Y* from *a* to 11, and from *f* to 1; the distance *x X* from *b* to 10, and from *g* to 2; *w W* from *c* to 9, and from *h* to 3; *t T* from *d* to 8, and from *i* to 4; *s S* from *e* to 7, and from *n* to 5. Then laying a ruler to the center *Z*, draw the forenoon hour-lines through the points 11, 10, 9, 8, 7; and laying it to the center *z*, draw the afternoon lines through the points 1, 2, 3, 4, 5; continuing the forenoon lines of VII and VIII through the center *Z*, to the opposite side of the dial, for the like afternoon hours; and the afternoon lines IIII and V through the center *z*, to the opposite side, for the like morning hours. Set the hours to these lines as in the figure, and then erect the stile or gnomon, and the horizontal dial will be finished.

To construct a south dial, draw the line *V Z*, making an angle with the meridian *Z L* equal to the co-latitude of your place; and proceed in all respects as in the above horizontal dial for the same latitude, reversing the hours as in Fig. 2, and making the elevation of the gnomon equal to the co-latitude. *South dial.*

Perhaps it may not be unacceptable to explain the method of constructing the dialing lines, and some others; which is as follows.

With any opening of the compasses, as *E A*, according to the intended length of the scale, describe the circle *A D C B*, and cross it at right angles by the diameters *C E A* and *D E B*. Divide the quadrant *A B* first into 9 equal parts, and then each part into 10; so shall the quadrant be divided into 90 equal parts or degrees. Draw the

Plate XXII. Fig. 1. *Dialing lines*, how constructed.

the right line *AFB* for the chord of this quadrant, and setting one foot of the compasses in the point *A*, extend the other to the several divisions of the quadrant, and transfer these divisions to the line *AFB* by the arcs 10 10, 20 20, &c. and this will be a line of chords, divided into 90 unequal parts; which, if transferred from the line back again to the quadrant, will divide it equally. It is plain by the figure, that the distance from *A* to 60 in the line of chords, is just equal to *AE*, the radius of the circle from which that line is made; for if the arc 60 60 be continued, of which *A* is the center, it goes exactly through the center *E* of the arc *AB*.

And therefore, in laying down any number of degrees on a circle, by the line of chords, you must first open the compasses so, as to take in just 60 degrees upon that line, as from *A* to 60: and then, with that extent, as a radius, describe a circle which will be exactly of the same size with that from which the line was divided: which done, set one foot of the compasses in the beginning of the chord line, as at *A*, and extend the other to the number of degrees you want upon the line, which extent, applied to the circle, will include the like number of degrees upon it.

Plate XXII.

Fig. 1. Dialing lines, now constructed.

Divide the quadrant *CD* into 90 equal parts, and from each point of division draw right lines, as *i*, *k*, *l*, &c. to the line *CE*; all perpendicular to that line, and parallel to *DE*, which will divide *EC* into a line of sines; and although these are seldom put among the dialing lines on a scale, yet they assist in drawing the line of latitudes. For, if a ruler be laid upon the point *D*, and over each division in the line of sines, it will divide the quadrant *CB* into 90 unequal parts,

as

as *B a*, *a b*, &c. ſhewn by the right lines 10 *a*, 20 *b*, 30 *c*, &c. drawn along the edge of the ruler. If the right line *B C* be drawn, ſubtending this quadrant, and the neareſt diſtances *B a*, *B b*, *B c*, &c. be taken in the compaſſes from *B*, and ſet upon this line in the ſame manner as directed for the line of chords, it will make a line of latitudes *B C*, equal in length to the line of chords *A B*, and of an equal number of diviſions, but very unequal as to their lengths.

Draw the right line *D G A*, ſubtending the quadrant *D A*; and parallel to it, draw the right line *r s*, touching the quadrant *D A* at the numeral figure 3. Divide this quadrant into ſix equal parts, as 1, 2, 3, &c. and through theſe points of diviſion draw right lines from the center *E* to the line *r s*, which will divide it at the points where the ſix hours are to be placed, as in the figure. If every ſixth part of the quadrant be ſubdivided into four equal parts, right lines drawn from the center through theſe points of diviſion, and continued to the line *r s*, will divide each hour upon it into quarters.

A dial on a card.

In Fig. 2. we have the repreſentation of a portable dial, which may be eaſily drawn on a card, and carried in a pocket-book. The lines *c d*, *a b* and *b c* of the gnomon muſt be cut quite through the card; and as the end *a b* of the gnomon is raiſed occaſionally above the plane of the dial, it turns upon the uncut line *c d* as on a hinge. The line dotted *A B* muſt be ſlit quite through the card, and the thread muſt be put through the ſlit, and have a knot tied behind, to keep it from being eaſily drawn out. On the other end of this thread is a ſmall plummet *D*, and on the middle of it a ſmall bead for ſhewing the hour of the day.

To rectify this dial, set the thread in th slit right against the day of the month, and stretch the thread from the day of the month over th angular point where the curve-lines meet at XII then shift the bead to that point on the thread and the dial will be rectified.

To find the hour of the day, raise the gnomo (no matter how much or how little) and hol the edge of the dial next the gnomon toward the sun, so as the uppermost edge of the shadow of the gnomon may just cover the *shadow-line* and the bead then playing freely on the face o the dial, by the weight of the plummet, wil shew the time of the day among the hour-lines as it is forenoon or afternoon.

To find the time of sun-rising and setting move the thread among the hour-lines, until i either covers some one of them, or lies paralle betwixt any two; and then it will cut the tim of sun-rising among the forenoon hours, and o sun-setting among the afternoon hours, on tha day of the year for which the thread is set in th scale of months.

To find the sun's declination, stretch the threa from the day of the month over the angula point at XII, and it will cut the sun's declina tion, as it is north or south, for that day, in th arched scale of north and south declination.

To find on what days the sun enters th signs: when the bead, as above rectified, move along any of the curve lines which have th signs of the zodiac marked upon them, th sun enters those signs on the days pointed out b the thread in the scale of months.

The construction of this dial is very eas especially if the reader compares it all alon

wi

with Fig. 3. as he reads the following explanation of that figure.

Draw the occult line *AB* parallel to the top of the card, and cross it at right angles with the six o'clock line *ECD*; then upon *C*, as a center, with the radius *CA*, describe the semicircle *AEL*, and divide it into 12 equal parts (beginning at *A*) as *Ar*, *As*, &c. and from these points of division, draw the hour-lines *r*, *s*, *t*, *u*, *v*, *E*, *w*, and *x*, all parallel to the six o'clock line *EC*. If each part of the semicircle be subdivided into four equal parts, they will give the half-hour lines and quarters, as in Fig. 2. Draw the right line *ASDo*, making the angle *SAB* equal to the latitude of your place. Upon the center *A* describe the arch *RST*, and set off upon it the arcs *SR* and *ST*, each equal to $23\frac{1}{2}$ degrees, for the sun's greatest declination; and divide them into $23\frac{1}{2}$ equal parts, as in Fig. 2. Through the intersection *D* of the lines *ECD* and *ADo*, draw the right line *FDG* at right angles to *ADo*. Lay a ruler to the points *A* and *R*, and draw the line *ARF* through $23\frac{1}{2}$ degrees of south declination in the arc *SR*; and then laying the ruler to the points *A* and *T*, draw the line *ATG* through $23\frac{1}{2}$ degrees of north declination in the arc *ST*: so shall the lines *ARF* and *ATG* cut the line *FDG* in the proper length for the scale of months. Upon the center *D*, with the radius *DF*, describe the semicircle *FoG*; and divide it into six equal parts, *Fm*, *mn*, *no*, &c. and from these points of division draw the right lines *mh*, *ni*, *pk*, and *ql*, each parallel to *oD*. Then setting one foot of the compasses in the point *F*, extend the other to *A*, and describe the arc *AzH* for the tropic of ♑: with the same extent, setting one foot in *G*, describe

Fig. 3.

ſcribe the arc *AEO* for the tropic of ♋. Next ſetting one foot in the point *b*, and extending the other to *A*, deſcribe the arc *ACI* for the beginnings of the ſigns ♒ and ♐; and with the ſame extent, ſetting one foot in the point *l*, deſcribe the arc *AN* for the beginnings of the ſigns ♊ and ♌. Set one foot in the point *i*, and having extended the other to *A*, deſcribe the arc *AK* for the beginnings of the ſigns ♓ and ♏; and with the ſame extent, ſet one foot in *k*, and deſcribe the arc *AM* for the beginnings of the ſigns ♉ and ♍. Then, ſetting one foot in the point *D*, and extending the other to *A*, deſcribe the curve *AL* for the beginnings of ♈ and ♎; and the ſigns will be finiſhed. This done, lay a ruler from the point *A* over the ſun's declination in the arch *RST* (found by the following table) for every fifth day of the year; and where the ruler cuts the line *FDG*, make marks; and place the days of the months right againſt theſe marks, in the manner ſhewn by Fig. 2. Laſtly, draw the ſhadow-line *PQ* parallel to the occult line *AB*; make the gnomon, and ſet the hours to their reſpective lines, as in Fig. 2. and the dial will be finiſhed.

Fig. 4.

An univerſal dial.

There are ſeveral kinds of dials, which are called *univerſal*, becauſe they ſerve for all latitudes. Of theſe, the beſt one that I know, is Mr. *Pardie*'s, which conſiſts of three principal parts; the firſt whereof is called the *horizontal plane (A)*, becauſe in the practice it muſt be parallel to the horizon. In this plane is fixt an upright pin, which enters into the edge of the ſecond part *BD*, called the *meridional plane*; which is made of two pieces, the loweſt whereof *(B)* is called the *quadrant*, becauſe it contains a quarter of a circle, divided into 90 degrees; and

it

it is only into this part, near *B*, that the pin enters. The other piece is a *semicircle* (*D*) adjusted to the quadrant, and turning in it by a groove, for raising or depressing the diameter (*E F*) of the semicircle, which diameter is called the *axis* of the instrument. The third piece is a *circle* (*G*), divided on both sides into 24 equal parts, which are the hours. This circle is put upon the meridional plane so, that the axis (*E F*) may be perpendicular to the circle; and the point *C* be the common center of the circle, semicircle, and quadrant. The straight edge of the semicircle is chamfered on both sides to a sharp edge, which passes through the center of the circle. On one side of the chamfered part, the first six months of the year are laid down, according to the sun's declination for their respective days, and on the other side the last six months. And against the days on which the sun enters the signs, there are straight lines drawn upon the semicircle, with the characters of the signs marked upon them. There is a black line drawn along the middle of the upright edge of the quadrant, over which hangs a thread (*H*), with its plummet (*I*), for leveling the instrument. *N. B.* From the 23d of September to the 20th of March, the upper surface of the circle must touch both the center *C* of the semicircle, and the line of ♈ and ♎; and from the 20th of March to the 23d of September, the lower surface of the circle must touch that center and line.

To find the time of the day by this dial. Having set it on a level place in sun-shine, and adjusted it by the leveling screws *k* and *l*, until the plumb-line hangs over the black line upon the edge of the quadrant, and parallel to the said edge; move the semicircle in the quadrant, until the

the line of ♈ and ♎ (where the circle touches) comes to the latitude of your place in the quadrant: then, turn the whole meridional plane *B D*, with its circle *G*, upon the horizontal plane *A*, until the edge of the shadow of the circle falls precisely on the day of the month in the semicircle; and then, the meridional plane will be due north and south, the axis *EF* will be parallel to the axis of the world, and will cast a shadow upon the true time of the day, among the hours on the circle.

N. B. As, when the instrument is thus rectified, the quadrant and semicircle are in the plane of the meridian, so the circle is then in the plane of the equinoctial. Therefore, as the sun is above the equinoctial in summer (in northern latitudes), and below it in winter; the axis of the semicircle will cast a shadow on the hour of the day, on the upper surface of the circle, from the 20th of March to the 23d of September: and from the 23d of September, to the 20th of March, the hour of the day will be determined by the shadow of the semicircle, upon the lower surface of the circle. In the former case, the shadow of the circle falls upon the day of the month, on the lower part of the diameter of the semicircle; and in the latter case, on the upper part.

The method of laying down the months and signs upon the semicircle, is as follows. Draw the right line *A C B*, equal to the diameter of the Fig. 5. semicircle *A D B*, and cross it in the middle at right angles with the line *E C D*, equal in length to *A D B*; then *E C* will be the radius of the circle *F C G*, which is the same as that of the semicircle. Upon *E*, as a center, describe the circle *F C G*, on which set off the arcs *C b* and *C i*, each equal to $23\frac{1}{2}$ degrees, and divide them accordingly into that number, for the sun's declination.

clination. Then, laying the edge of a ruler over the center E, and also over the sun's declination for every * fifth day of each month (as in the card dial) mark the points on the diameter AB of the semicircle from a to g, which are cut by the ruler; and *there* place the days of the months accordingly, answering the sun's declination. This done, setting one foot of the compasses in C, and extending the other to a or g, describe the semicircle $a\,b\,c\,d\,e\,f\,g$; which divide into six equal parts, and through the points of division draw right lines, parallel to CD, for the beginning of the sines (of which one half are on one side of the semicircle, and the other half on the other side) and set the characters of the signs to their proper lines, as in the figure.

The following table shews the sun's place and declination, in degrees and minutes, at the noon of every day of the second year after leap-year; which is a mean between those of leap-year itself, and the first and third years after. It is useful for inscribing the months and their days on sun-dials; and also for finding the latitudes of places, according to the methods prescribed after the table.

* The intermediate days may be drawn in by hand, if the space be large enough to contain them.

A Table shewing the sun's place and declination.

	January.					February.				
Days.	Sun's Pl.		Sun's Dec.		Days.	Sun's Pl.		Sun's Dec.	
	D.	M.	D.	M.		D.	M.	D.	M.
1	11 ♑	5	23 S	1	1	12 ♒	38	17 S	2
2	12	6	22	55	2	13	39	16	45
3	13	8	22	49	3	14	40	16	27
4	14	9	22	43	4	15	41	16	10
5	15	10	22	37	5	16	41	15	51
6	16	11	22	29	6	17	42	15	33
7	17	12	22	22	7	18	43	15	14
8	18	13	22	14	8	19	43	14	55
9	19	14	22	5	9	20	44	14	36
10	20	16	21	56	10	21	45	14	17
11	21	17	21	47	11	22	45	13	57
12	22	18	21	37	12	23	46	13	37
13	23	19	21	27	13	24	46	13	17
14	24	20	21	17	14	25	47	12	57
15	25	21	21	6	15	26	47	12	36
16	26	22	20	54	16	27	48	12	15
17	27	24	20	43	17	28	48	11	54
18	28	25	20	30	18	29	48	11	33
19	29	26	20	18	19	0 ♓	49	11	12
20	0 ♒	27	20	5	20	1	49	10	50
21	1	28	19	52	21	2	50	10	29
22	2	29	19	38	22	3	50	10	7
23	3	30	19	24	23	4	50	9	45
24	4	31	19	10	24	5	51	9	23
25	5	32	18	55	25	6	51	9	0
26	6	33	18	40	26	7	51	8	38
27	7	34	18	24	27	8	51	8	16
28	8	35	18	9	28	9	51	7	53
29	9	35	17	53					
30	10	36	17	36					
31	11	37	17	19					

In these Tables N signifies north declination, and S south.

A Table

A Table shewing the sun's place and declination.

	March.					April.			
Days.	Sun's Pl.		Sun's Dec.		Days.	Sun's Pl		Sun's Dec.	
	D.	M.	D.	M.		D.	M.	D.	M.
1	10 ♓	52	7 S	30	1	11 ♈	38	4 N	36
2	11	52	7	7	2	12	37	4	59
3	12	52	6	44	3	13	36	5	22
4	13	52	6	21	4	14	35	5	45
5	14	52	5	58	5	15	34	6	8
6	15	52	5	35	6	16	33	6	31
7	16	51	5	12	7	17	31	6	53
8	17	51	4	48	8	18	30	7	16
9	18	51	4	25	9	19	29	7	38
10	19	51	4	2	10	20	28	8	0
11	20	51	3	38	11	21	27	8	22
12	21	50	3	14	12	22	25	8	44
13	22	50	2	51	13	23	24	9	6
14	23	50	2	27	14	24	23	9	28
15	24	49	2	4	15	25	21	9	49
16	25	49	1	40	16	26	20	10	11
17	26	48	1	16	17	27	18	10	32
18	27	48	0	53	18	28	17	10	53
19	28	48	0	29	19	29	15	11	14
20	29	47	0	5	20	0 ♉	14	11	34
21	0 ♈	47	0 N	19	21	1	12	11	55
22	1	46	0	42	22	2	11	12	15
23	2	45	1	6	23	3	9	12	35
24	3	45	1	29	24	4	7	12	55
25	4	44	1	53	25	5	6	13	14
26	5	43	2	17	26	6	4	13	34
27	6	42	2	40	27	7	2	13	53
28	7	42	3	3	28	8	0	14	12
29	8	41	3	27	29	8	59	14	30
30	9	40	3	50	30	9	57	14	49
31	10	39	4	13					

A Table shewing the sun's place and declination.

May.					June.				
Days.	Sun's Pl.		Sun's Dec.		Days.	Sun's Pl.		Sun's Dec.	
	D.	M.	D.	M.		D.	M.	D.	M.
1	10 ♉	55	15 N	7	1	10 ♊	44	22 N	5
2	11	53	15	25	2	11	41	22	13
3	12	51	15	43	3	12	39	22	21
4	13	49	16	0	4	13	36	22	28
5	14	47	16	18	5	14	34	22	35
6	15	45	16	35	6	15	31	22	41
7	16	43	16	51	7	16	28	22	47
8	17	41	17	8	8	17	26	22	53
9	18	39	17	24	9	18	23	22	58
10	19	36	17	40	10	19	20	23	3
11	20	34	17	55	11	20	18	23	7
12	21	32	18	10	12	21	15	23	11
13	22	30	18	25	13	22	12	23	15
14	23	28	18	40	14	23	9	23	18
15	24	25	18	54	15	24	7	23	20
16	25	23	19	8	16	25	4	23	22
17	26	21	19	22	17	26	1	23	24
18	27	19	19	35	18	26	58	23	26
19	28	16	19	48	19	27	56	23	27
20	29	14	20	1	20	28	53	23	28
21	0 ♊	11	20	13	21	29	50	23	28
22	1	9	20	25	22	0 ♋	47	23	28
23	2	7	20	37	23	1	45	23	28
24	3	4	20	48	24	2	42	23	27
25	4	2	20	59	25	3	39	23	26
26	4	59	21	10	26	4	36	23	24
27	5	57	21	20	27	5	33	23	21
28	6	54	21	30	28	6	31	23	19
29	7	52	21	39	29	7	28	23	16
30	8	49	21	49	30	8	25	23	12
31	9	47	21	57					

A Table shewing the sun's place and declination.

July.					August.				
Days.	Sun's Pl.		Sun's Dec.		Days	Sun's Pl.		Sun's Dec.	
	D.	M.	D.	M.		D.	M.	D.	M.
1	9 ♋	22	23 N	8	1	8 ♌	58	18 N	2
2	10	19	23	4	2	9	55	17	47
3	11	16	23	0	3	10	53	17	32
4	12	14	22	55	4	11	50	17	16
5	13	11	22	49	5	12	48	17	0
6	14	8	22	43	6	13	45	16	43
7	15	5	22	37	7	14	43	16	26
8	16	0	22	30	8	15	41	16	9
9	17	2	22	23	9	16	38	15	52
10	17	57	22	16	10	17	36	15	35
11	18	54	22	8	11	18	33	15	17
12	19	51	22	0	12	19	31	14	59
13	20	49	21	52	13	20	29	14	41
14	21	46	21	43	14	21	26	14	23
15	22	43	21	33	15	22	24	14	4
16	23	40	21	22	16	23	22	13	44
17	24	38	21	14	17	24	20	13	26
18	25	35	21	3	18	25	17	13	7
19	26	32	20	52	19	26	15	12	47
20	27	29	20	41	20	27	13	12	27
21	28	27	20	30	21	28	11	12	7
22	29	24	20	18	22	29	9	11	47
23	0 ♌	21	20	6	23	0 ♍	7	11	27
24	1	19	19	54	24	1	5	11	6
25	2	16	19	41	25	2	3	10	46
26	3	13	19	28	26	3	1	10	25
27	4	11	19	14	27	3	59	10	4
28	5	8	19	1	28	4	57	9	43
29	6	6	18	46	29	5	55	9	21
30	7	5	18	32	30	6	53	9	0
31	8	0	18	17	31	7	51	8	38

A Table shewing the sun's place and declination.

September.					October.				
Days.	Sun's Pl.		Sun's Dec.		Days.	Sun's Pl.		Sun's Dec.	
	D.	M.	D.	M.		D.	M.	D.	M.
1	8 ♍	49	8 N	16	1	8 ♎	8	3 S	14
2	9	47	7	55	2	9	7	3	37
3	10	40	7	33	3	10	7	4	1
4	11	44	7	10	4	11	6	4	24
5	12	42	6	48	5	12	5	4	47
6	13	40	6	26	6	13	4	5	10
7	14	39	6	3	7	14	4	5	33
8	15	37	5	41	8	15	3	5	56
9	16	35	5	18	9	16	3	6	19
10	17	34	4	55	10	17	2	6	42
11	18	32	4	32	11	18	1	7	5
12	19	31	4	9	12	19	1	7	27
13	20	29	3	46	13	20	0	7	50
14	21	28	3	23	14	21	0	8	12
15	22	26	3	0	15	22	0	8	35
16	23	25	2	37	16	23	0	8	57
17	24	25	2	14	17	23	59	9	19
18	25	22	1	50	18	24	59	9	41
19	26	21	1	27	19	25	58	10	3
20	27	20	1	4	20	26	58	10	24
21	28	19	0	40	21	27	58	10	46
22	29	17	0	17	22	28	58	11	7
23	0 ♎	16	0 S	6	23	29	58	11	28
24	1	15	0	30	24	0 ♏	58	11	49
25	2	14	0	53	25	1	58	12	10
26	3	13	1	17	26	2	58	12	31
27	4	12	1	40	27	3	58	12	51
28	5	11	2	4	28	4	58	13	12
29	6	10	2	27	29	5	58	13	32
30	7	9	2	50	30	6	58	13	51
					1	7	58	14	11

A Table

A Table shewing the sun's place and declination.

November					December				
Days.	Sun's Pl.		Sun's Dec.		Days.	Sun's Pl.		Sun's Dec.	
	M.	D.	D.	M.		D.	M.	D.	M.
1	8 ♏	58	14 S	30	1	9 ♐	16	21 S	52
2	9	58	14	50	2	10	17	22	1
3	10	59	15	8	3	11	18	22	10
4	11	59	15	27	4	12	19	22	18
5	12	59	15	45	5	13	20	22	26
6	13	59	16	3	6	14	21	22	33
7	15	0	16	21	7	15	22	22	40
8	16	0	16	39	8	16	23	22	46
9	17	0	16	56	9	17	24	22	52
10	18	1	17	13	10	18	25	22	58
11	19	1	17	30	11	19	26	23	3
12	20	2	17	46	12	20	27	23	8
13	21	2	18	2	13	21	28	23	12
14	22	3	18	18	14	22	29	23	15
15	23	4	18	34	15	23	30	23	18
16	24	4	18	49	16	24	31	23	21
17	25	5	19	4	17	25	3[illegible]	23	24
18	26	5	19	18	18	26	34	23	26
19	27	6	19	32	19	27	35	23	27
20	28	7	19	46	20	28	36	23	28
21	29	7	19	59	21	29	37	23	28
22	0 ♐	8	20	12	22	0 ♑	38	23	28
23	1	9	20	25	23	1	40	23	28
24	2	10	20	37	24	2	41	23	27
25	3	11	20	49	25	3	42	23	25
26	4	11	21	1	26	4	43	23	23
27	5	12	21	12	27	5	44	23	21
28	6	13	21	23	28	6	46	23	18
29	7	14	21	33	29	7	47	23	15
30	8	15	21	43	30	8	48	23	11
					31	9	49	23	6

To find the latitude of any place by observation.

The latitude of any place is equal to th elevation of the pole above the horizon of tha place. Therefore it is plain, that if a ſtar wa fixt in the pole, there would be nothing re quired to find the latitude, but to take the al titude of that ſtar with a good inſtrument. Bu although there is no ſtar in the pole, yet th latitude may be found by taking the greate and leaſt altitude of any ſtar that never ſets: fo if half the difference between theſe altitudes b added to the leaſt altitude, or ſubtracted from the greateſt, the ſum or remainder will be equa to the altitude of the pole at the place of obſer vation.

But becauſe the length of the night muſt b more than 12 hours, in order to have two ſuc obſervations; the ſun's meridian altitude an declination are generally made uſe of for finding the latitude, by means of its complement, whic is equal to the elevation of the equinoctial abov the horizon; and if this complement be ſub tracted from 90 degrees, the remainder will b the latitude: concerning which, I think, th following rules take in all the various caſes.

1. If the ſun has north declination, and is on the meridian, and to the ſouth of your place ſubtract the declination from the meridian alti tude (taken by a good quadrant) and the re mainder is the height of the equinoctial or com plement of the latitude north.

EXAM-

EXAMPLE.

Suppose {	The sun's meridian altitude	42°	20′	South
	And his declination, subt.	10	15	North
Rem. the complement of the lat.		32	5	
Which subtract from — —		90	0	
And the remainder is the latitude		57	55	North.

2. If the sun has south declination, and is southward of your place at noon, add the declination to the meridian altitude; the sum, if less than 90 degrees, is the complement of the latitude north: but if the sum exceeds 90 degrees, the latitude is south; and if 90 be taken from that sum, the remainder will be the latitude.

EXAMPLES.

The sun's meridian altitude —	65°	10′	South
The sun's declination, add —	15	30	South
Complement of the latitude	80	40	
Subtract from — —	90	0	
Remains the latitude —	9	20	North

The sun's meridian altitude	80°	40′	South
The sun's declination, add —	20	10	South
The sum is - - - - - -	100	50	
From which subtract - - -	90	0	
Remains the latitude — —	10	50	South.

3. If

3. If the ſun has north declination, and is on the meridian north of your place, add the declination to the north meridian altitude; the ſum, if leſs than 90 degrees, is the complement of the latitude ſouth: but if the ſum is more than 90 degrees, ſubtract 90 from it, and the remainder is the latitude north.

EXAMPLES.

Sun's meridian altitude —	60°	30′	North
Sun's declination, add —	20	10	North
Complement of the latitude -	80	40	
Subtract from - - - - -	90	0	
Remains the latitude - - -	9	20	South.

Sun's meridian altitude - -	70°	20′	North
Sun's declination, add - -	23	20	North
The ſum is - - - - - -	93	40	
From which ſubtract - - -	90	0	
Remains the latitude - - -	3	40	North.

4. If the ſun has ſouth declination, and is north of your place at noon, ſubtract the declination from the north meridian altitude, and the remainder is the complement of the latitude ſouth.

EXAMPLE.

Sun's meridian altitude - - -	50°	30′	North
Sun's declination, subtract - -	20	10	South
Complement of the latitude -	32	20	
Subtract this from - - - -	90	0	
And the remainder is the latitude	57	40	South.

5. If the sun has no declination, and is south of your place at noon, the meridian altitude is the complement of the latitude north: but if the sun be then north of your place, his meridian altitude is the complement of the latitude south.

EXAMPLES.

Sun's meridian altitude - -	38°	30′	South
Subtract from - - - - - -	90	0	
Remains the latitude - -	51	30	North.

Sun's meridian altitude - -	38°	30′	North
Subtract from - - - - -	90	0	
Remains the latitude - -	51	30	South.

6. If you observe the sun beneath the pole, subtract his declination from 90 degrees, and add the remainder to his altitude; and the sum is the latitude.

EXAM-

EXAMPLE.

Sun's declination - - - -	20° 30′	
Subtract from - - - - -	90 0	
Remains - - - - - - -	69 30	add
Sun's altitude below the pole -	10 20	
The sum is the latitude - -	79 50.	

Which is north or south, according as the sun's declination is north or south: for when the sun has south declination, he is never seen below the north pole; nor is he ever seen below the south pole, when his declination is north.

7. If the sun be in the zenith at noon, and at the same time has no declination, you are then under the equinoctial, and so have no latitude.

8. If the sun be in the zenith at noon, and has declination, the declination is equal to the latitude, north or south. These two cases are so plain, that they require no examples.

LECT. XI.

Of Dialing.

HAVING shewn in the preceding Lecture how to make sun-dials by the assistance of a good globe, or of a dialing scale, we shall now proceed to the method of constructing dials arithmetically; which will be more agreeable to those who have learnt the elements of trigo-

trigonometry, because globes and ſcales can never be ſo accurate as the logarithms, in finding the angular diſtances of the hours. Yet, as a globe may be found exact enough for ſome other requiſites in dialing, we ſhall take it in occaſionally.

The conſtruction of ſun dials on all planes whatever, may be included in one general rule: intelligible, if that of a horizontal dial for any given latitude be well underſtood. For there is no plane, however obliquely ſituated with reſpect to any given place, but what is parallel to the horizon of ſome other place; and therefore, if we can find that other place by a problem on the terreſtrial globe, or by a trigonometrical calculation, and conſtruct a horizontal dial for it; that dial, applied to the plane where it is to ſerve, will be a true dial for that place.—Thus, an erect direct ſouth dial in $51\frac{1}{2}$ degrees north latitude, would be a horizontal dial on the ſame meridian, 90 degrees ſouthward of $51\frac{1}{2}$ degrees north latitude; which falls in with $38\frac{1}{2}$ degrees of ſouth latitude. But if the upright plane declines from facing the ſouth at the given place, it would ſtill be a horizontal plane 90 degrees from that place; but for a different longitude: which would alter the reckoning of the hours accordingly.

CASE I.

1. Let us ſuppoſe that an upright plane at London declines 36 degrees weſtward from facing the ſouth; and that it is required to find a place on the globe, to whoſe horizon the ſaid plane is parallel; and alſo the difference of longitude between London and that place.

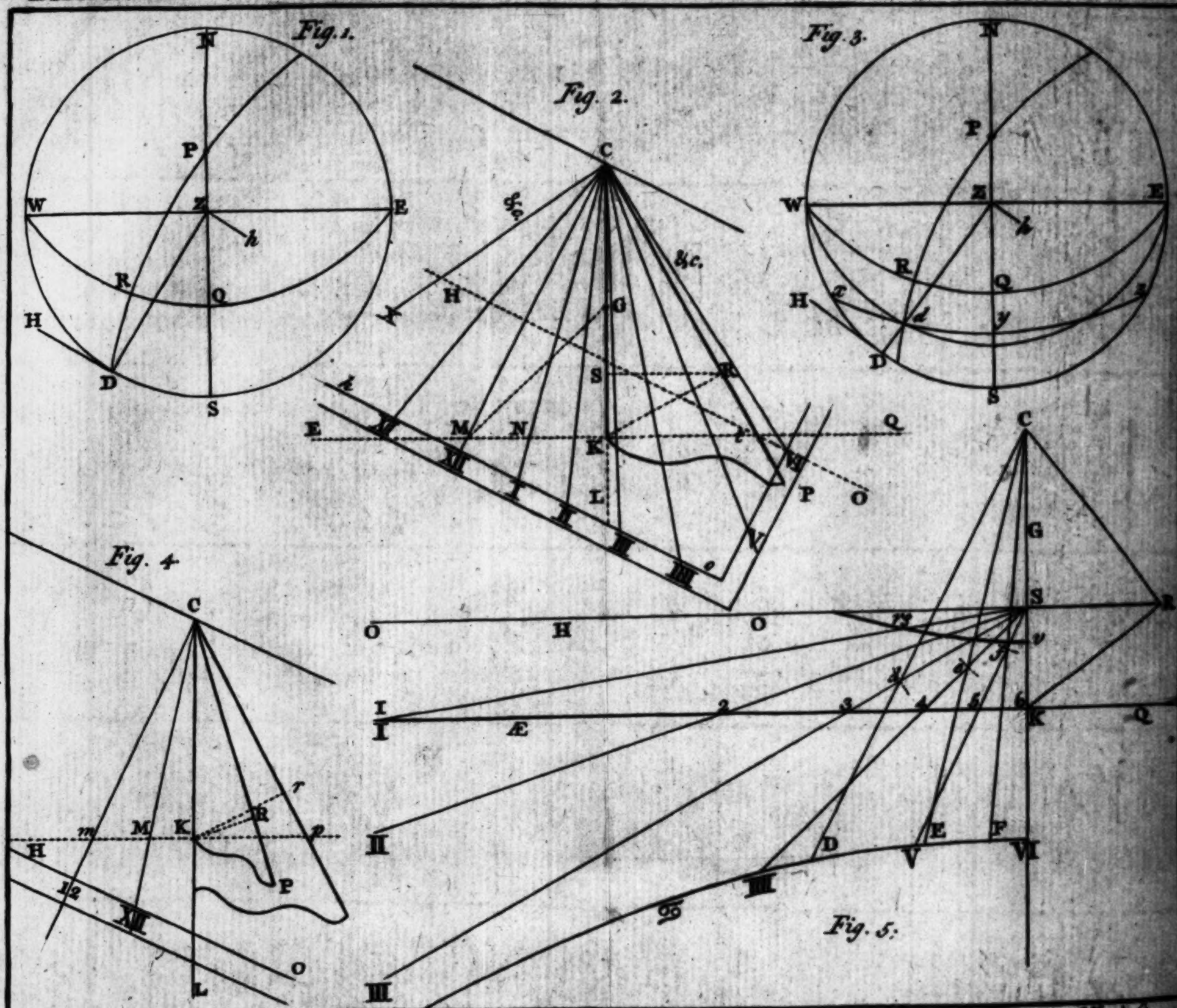
Rectify

Rectify the globe to the latitude of London, and bring London to the zenith under the brass meridian, then that point of the globe which lies in the horizon at the given degree of declination (counted westward from the south point of the horizon) is the place at which the above-mentioned plane would be horizontal.—Now, to find the latitude and longitude of that place, keep your eye upon the place, and turn the globe eastward, until it comes under the graduated edge of the brass meridian; then, the degree of the brass meridian that stands directly over the place, is its latitude; and the number of degrees in the equator, which are intercepted between the meridian of London and the brass meridian, is the place's difference of longitude.

Thus, as the latitude of London is $51\frac{1}{2}$ degrees north, and the declination of the plane is 36 degrees west; I elevate the north pole $51\frac{1}{2}$ degrees above the horizon, and turn the globe until London comes to the zenith, or under the graduated edge of the meridian; then, I count 36 degrees on the horizon westward from the south point, and make a mark on that place of the globe over which the reckoning ends, and bringing the mark under the graduated edge of the brass meridian, I find it to be under $30\frac{1}{4}$ degrees in south latitude: keeping it there, I count in the equator the number of degrees between the meridian of London and the brasen meridian (which now becomes the meridian of the required place) and find it to be $42\frac{3}{4}$. Therefore an upright plane at London, declining 36 degrees westward from the south, would be a horizontal plane at that place, whose latitude is $30\frac{1}{4}$ degrees south of the equator, and longitude $42\frac{3}{4}$ degrees west of the meridian of London.

Which

PLATE XXIII.



J. Ferguson del.

J. Lynde sc.

Which difference of longitude being converted into time, is 2 hours 51 minutes.

The vertical dial declining westward 36 degrees at London, is therefore to be drawn in all respects as a horizontal dial for south latitude 30¼ degrees; save only, that the reckoning of the hours is to anticipate the reckoning on the horizontal dial, by 2 hours 51 minutes: for so much sooner will the sun come to the meridian of London, than to the meridian of any place whose longitude is 42¾ degrees west from London.

2. But to be more exact than the globe will shew us, we shall use a little trigonometry.

Let $NESW$ be the horizon of London, whose zenith is Z, and P the north pole of the sphere; and let $Z\,b$ be the position of a vertical plane at Z, declining westward from S (the south) by an angle of 36 degrees; on which plane an erect dial for London at Z is to be described. Make the semidiameter ZD perpendicular to $Z\,b$, and it will cut the horizon in D, 36 degrees west of the south S. Then, a plane in the tangent HD, touching the sphere in D, will be parallel to the plane $Z\,h$; and the axis of the sphere will be equally inclined to both these planes. Plate XXIII. Fig. 1.

Let $W\mathfrak{Q}E$ be the equinoctial, whose elevation above the horizon of Z (London) is 38½ degrees; and PRD be the meridian of the place D, cutting the equinoctial in R. Then, it is evident, that the arc RD is the latitude of the place D (where the plane $Z\,b$ would be horizontal) and the arc $R\mathfrak{Q}$ is the difference of longitude of the planes $Z\,b$ and DH.

In the spherical triangle WDR, the arc WD is given, for it is the complement of the plane's

decli-

declination from *S* the south; which comple
ment is 54° (viz. 90°—36°:) the angle at *R*
in which the meridian of the place *D* cuts th
equator, is a right angle; and the angle *RW*
measures the elevation of the equinoctial abov
the horizon of *Z*, namely, $38\frac{1}{2}$ degrees. Sa
therefore, as radius is to the co-sine of th
plane's declination from the south, so is the co
sine of the latitude of *Z* to the sine of *RD* th
latitude of *D*: which is of a different denomi
nation from the latitude of *Z*, because *Z* and *D*
are on different sides of the equator.

As radius	- - - - - -	10.00000
To co-sine	36° 0′ = RQ	9.90796
So co-sine	51° 30′ = QZ	9.79415
To sine	30° 14′ = DR	(9.70211) =

the latitude of *D*, whose horizon is parallel t
the vertical plane *Z b* at *Z*.

N. B. When radius is made the first term, i
may be omitted, and then, by subtracting i
mentally from the sum of the other two, th
operation will be shortened. Thus, in the pre
sent case,

To the logarithmic sine of WR=*	54° 0′	9.9079
Add the logarithmic sine of RD=†	38° 30′	9.7941
Their sum — radius - - - - - -		9.7021

gives the same solution as above. And we sha
keep to this method in the following part of th
work.

* The co-sine of 36° 0′, or of RQ.
† The co-sine of 51° 30′, or of QZ.

To find the difference of longitude of the places D and Z, say, as radius is to the co-sine of $38\frac{1}{2}$ degrees, the height of the equinoctial at Z, so is the co-tangent of 36 degrees, the plane's declination, to the co-tangent of the difference of longitudes. Thus,

To the logarithmic sine of *	51° 30′	9.89354
Add the logarithmic tang. of †	54° 0′	10.13874
Their sum — radius - - -		10.03228

is the nearest tangent of 47° 8′ = WR; which is the co-tangent of 42° 52′ = RQ, the difference of longitude sought. Which difference, being reduced to time, is 2 hours $51\frac{1}{2}$ minutes.

3. And thus having found the exact latitude and longitude of the place D, to whose horizon the vertical plane at Z is parallel, we shall proceed to the construction of a horizontal dial for the place D, whose latitude is 30° 14′ south; but anticipating the time at D by 2 hours 51 minutes (neglecting the $\frac{1}{2}$ minute in practice) because D is so far westward in longitude from the meridian of London; and this will be a true vertical dial at London, declining westward 36 degrees.

Assume any right line CSL for the substile of the dial, and make the angle KCP equal to the latitude of the place (viz. 30° 14′) to whose horizon the plane of the dial is parallel; then CRP will be the axis of the stile, or edge that casts the shadow on the hours of the day, in the dial. This done, draw the contingent line EQ, cutting the substilar line at right angles in K; Fig. 2.

* The co-sine of 38° 30′, or of WDR.
† The co-tangent of 36°, or of DW.

 and

and from K make KR perpendicular to the axis CRP. Then KG ($=KR$) being made radius, that is, equal to the chord of 60° or tangent of 45° on a good ſector, take 42° 52′ (the difference of longitude of the places Z and D) from the tangents, and having ſet it from K to M, draw CM for the hour-line of XII. Take KN equal to the tangent of an angle leſs by 15 degrees than KM; that is, the tangent 27° 52′; and through the point N draw CN for the hour-line of I. The tangent of 12° 52′ (which is 15° leſs than 27° 52′) ſet off the ſame way, will give a point between K and N, through which the hour-line of II is to be drawn. The tangent of 2° 8′ (the difference between 45° and 42° 52′) placed on the other ſide of CL, will determine the point through which the hour-line of III is to be drawn: to which 2° 8′, if the tangent of 15° be added, it will make 17° 8′; and this ſet off from K towards Q on the line EQ, will give the point for the hour-line of IIII: and ſo of the reſt.—The forenoon hour-lines are drawn the ſame way, by the continual addition of the tangents 15°, 30°, 45°, &c. to 42° 52 (=the tangent of KM) for the hours of XI, X, IX, &c. as far as neceſſary; that is, until there be five hours on each ſide of the ſubſtile. The ſixth hour, accounted from that hour or part of the hour on which the ſubſtile falls, will be always in a line perpendicular to the ſubſtile, and drawn through the center C.

4. In all erect dials, CM, the hour-line of XII, is perpendicular to the horizon of the place for which the dial is to ſerve: for that line is the interſection of a vertical plane with the plane of the meridian of the place, both which are perpendicular to the plane of the horizon:

horizon: and any line HO, or ho, perpendicular to CM, will be a horizontal line on the plane of the dial, along which line the hours may be numbered; and CM being set perpendicular to the horizon, the dial will have its true position.

5. If the plane of the dial had declined by an equal angle toward the east, its description would have differed only in this, that the hour-line of XII would have fallen on the other side of the substile CL, and the line HO would have a subcontrary position to what it has in this figure.

6. And these two dials, with the upper points of their stiles turned toward the north pole, will serve for the other two planes parallel to them; the one declining from the north toward the east, and the other from the north toward the west, by the same quantity of angle. The like holds true of all dials in general, whatever be their declination and obliquity of their planes to the horizon.

CASE II

7. If the plane of the dial not only *declines*, but also *reclines*, or *inclines*. Suppose its declination from fronting the south S be equal to the arc SD on the horizon; and its reclination be equal to the arc Dd of the vertical circle DZ: then it is plain, that if the quadrant of altitude ZdD, on the globe, cuts the point D in the horizon, and the reclination is counted upon the quadrant from D to d; the intersection of the hour-circle PRd, with the equinoctial WQE, will determine Rd, the latitude of the place d, Fig. 3.

whose horizon is parallel to the given plane *Zb* a
Z; and *RQ* will be the difference in longitud
of the planes at *d* and *Z*.

Trigonometrically thus: let a great circl
pass through the three points *W*, *d*, *E*; and i
the triangle *WDd*, right-angled at *D*, the side
WD and *Dd* are given; and thence the angl
DWd is found, and so is the hypothenuse *W*
Again, the difference, or the sum, of *DW*
and *DWR*, the elevation of the equinocti
above the horizon of *Z*, gives the angle *dWR*
and the hypothenuse of the triangle *WRd* wa
just now found; whence the sides *Rd* and *W*
are found, the former being the latitude of th
place *d*, and the latter the complement of *RQ*
the difference of longitude sought.

Thus, if the latitude of the place *Z* be 52° 1
north; the declination *SD* of the plane *Z*
(which would be horizontal at *d*) be 36°, an
the reclination be 15°, or equal to the arc *Dd*
the south latitude of the place *d*, that is, th
arc *Rd*, will be 15° 9′; and *RQ*, the diffe
rence of the longitude, 36° 2′. From the
data, therefore, let the dial (Fig. 4.) be de
scribed, as in the former example.

8. Only it is to be observed, that in the re
clining or inclining dials, the horizontal lin
will not stand at right angles to the hour-line o
XII, as in erect dials; but its position may b
found as follows.

Fig. 4. To the common substilar line *CKL*, o
which the dial for the place *d* was describe
draw the dial *Crpm* 12 for the place *D*, who
declination is the same as that of *d* (viz. the ar
SD;) and *HO*, perpendicular to *Cm*, the hour
line of XII on this dial, will be a horizontal lin
on the dial *CPRM* XII. For the declinatio
o

of both dials being the same, the horizontal line remains parallel to itself, while the erect position of one dial is reclined or inclined with respect to the position of the other.

Or, the position of the dial may be found by applying it to its plane, so as to mark the true hour of the day by the sun, as shewn by another dial; or by a clock, regulated by a true meridian line and equation table.

9. There are several other things requisite in the practice of dialing; the chief of which I shall give in the form of arithmetical rules, simple and easy to those who have learnt the elements of trigonometry. For in practical arts of this kind, arithmetick should be used as far as it can go; and scales never trusted to, except in the final construction, where they are absolutely necessary in laying down the calculated hour-distances on the plane of the dial. And although the inimitable artists of this metropolis have no occasion for such instructions, yet they may be of some use to students, and to private gentlemen who amuse themselves this way.

RULE I.

To find the angles which the hour-lines on any dial make with the substile.

To the logarithmic sine of the given latitude, or of the stile's elevation above the plane of the dial, add the logarithmic tangent of the hour * distance from the meridian, or from the

* That is, of 15, 30, 45, 60, 75°, for the hours of I, II, III, IIII, V in the afternoon: and XI, X, IX, VIII, VII in the forenoon.

† substile; and the sum *minus* radius will be th
logarithmic tangent of the angle sought.

For, in Fig. 2. *KC* is to *KM* in the rati
compounded of the ratio of *KC* to *KG* (=*KR*
and of *KG* to *KM*; which, making *CK* th
radius 10,000000, or 10,0000, or 10, or
are the ratio of 10,000000, or of 10,0000, o
of 10, or of 1, to $KG \times KM$.

Thus, in a horizontal dial, for latitud
51° 30′, to find the angular distance of XI i
the forenoon, or I in the afternoon, from XII

To the logarithmic sine of	51° 30′	9.89354
Add the logarithmic tang. of	15° 0′	9.42805

The sum — radius is - - - 9.32159
the logarithmic tangent of 11° 50′, or of t
angle which the hour-line of XI or I mak
with the hour of XII.

And by computing in this manner, with t
sine of the latitude, and the tangents of 3
45, 60, and 75°, for the hours of II, III, II
and V in the afternoon; or of X, IX, VII
and VII in the forenoon; you will find th
angular distances from XII to be 24° 18′, 38°
53° 35′, and 71° 6′; which are all that the
is occasion to compute for.——And these d
stances may be set off from XII by a line
chords; or rather, by taking 1000 from a sca
of equal parts, and setting that extent as a r
dius from *C* to XII; and then, taking 209

† In all horizontal dials, and erect north or south di
the substile and meridian are the same: but in all declini
dials, the substile line makes an angle with the meridian.

‡ In which case, the radius *CK* is supposed to be divid
into 1000000 equal parts.

the ſame parts (which, in the tables, are the natural tangent of 11° 50′) and ſetting them from XII to XI and to I, on the line *b o*, which is perpendicular to *C* XII: and ſo for the reſt of the hour-lines which, in the table of natural tangents, againſt the above diſtances, are 451, 782, 1355, and 2920, of ſuch equal parts from XII, as the radius *C* XII contains 1000. And laſtly, ſet off 1257 (the natural tangent of 51° 30′) for the angle of the ſtile's height, which is equal to the latitude of the place. Fig. 2.

The reaſon why I prefer the uſe of the tabular numbers, and of a ſcale decimally divided, to that of the line of chords, is becauſe there is the leaſt chance of miſtake and error in this way; and likewiſe, becauſe in ſome caſes it gives us the advantage of a *nonius'* diviſion.

In the univerſal ring-dial, for inſtance, the diviſions on the axis are the tangents of the angles of the ſun's declination placed on either ſide of the center. But inſtead of laying them down from a line of tangents, I would make a ſcale of equal parts, whereof 1000 ſhould anſwer exactly to the length of the ſemi-axis, from the center to the inſide of the equinoctial ring; and then lay down 434 of theſe parts toward each end from the center, which would limit all the diviſions on the axis, becauſe 434 are the natural tangent of 23° 29′. And thus, by a *nonius* affixed to the ſliding piece, and taking the ſun's declination from an Ephemeris, and the tangent of that declination from the table of natural tangents, the ſlider might be always ſet true to within two minutes of a degree.

And this ſcale of 434 equal parts might be placed right againſt the 23½ degrees of the ſun's declination, on the axis, inſtead of the ſun's

 place,

place, which is there of very little uſe. Fo[r] then, the ſlider might be ſet in the uſual way to the day of the month, for common uſe; bu[t] to the natural tangent of the declination, whe[n] great accuracy is required.

The like may be done wherever a ſcale o[f] ſines or tangents is required on any inſtrument.

RULE II.

The latitude of the place, the ſun's declination, an[d] his hour-diſtance from the meridian, being given to find (1.) *his altitude*; (2.) *his azimuth.*

Fig. 3. 1. Let d be the ſun's place, $d R$, his decli[-] nation; and in the triangle $P Z d$, $P d$ the ſum or the difference, of $d R$, and the quadrant $P R$ being given by the ſuppoſition, as alſo the com[-] plement of the latitude $P Z$, and the angl[e] $d P Z$, which meaſures the horary diſtance of [d] from the meridian; we ſhall (by Caſe 4. o[f] *Keill*'s Oblique ſpheric Trigonometry) find th[e] baſe $Z d$, which is the ſun's diſtance from th[e] zenith, or the complement of his altitude.

And (2.) As ſine $Z d$: ſine $P d$: : ſine $d P Z$ [:] $d Z P$, or of its ſupplement $D Z S$, the azimutha[l] diſtance from the ſouth.

Or, the practical rule may be as follows.

Write A for the ſine of the ſun's altitude, [L] and l for the ſine and co-ſine of the latitude, [D] and d for the ſine and co-ſine of the ſun's de[-] clination, and H for the ſine of the horary di[-] ſtance from VI.

Then the relation of H to A will have thre[e] varieties.

 1. Whe[n]

1. When the declination is toward the elevated pole, and the hour of the day is between XII and VI; it is $A = LD + Hld$, and $H = \frac{A - LD}{ld}$.

2. When the hour is after VI, it is $A = LD - Hld$, and $H = \frac{LD + A}{ld}$.

3. When the declination is toward the depressed pole, we have $A = Hld - LD$, and $H = \frac{A + LD}{ld}$.

Which theorems will be found useful, and expeditious enough for solving those problems in geography and dialing, which depend on the relation of the sun's altitude to the hour of the day.

EXAMPLE I.

Suppose the latitude of the place to be $51\frac{1}{2}$ degrees north; the time five hours distant from XII, that is, an hour after VI in the morning, or before VI in the evening; and the sun's declination 20° north. *Required the sun's altitude?*

Then, to log. L = log. sin. 51° 30′ 1.89354*
add log. D = log. sin. 20° 0′ 1.53405

Their sum - - - - - - - 1.42759
gives LD = logarithm of 0.267664, in the natural sines.

* Here we consider the radius as unity, and not 10.00000, by which, instead of the index 9 we have—1, as above: which is of no farther use, than making the work a little easier.

And,

And, to	log. H = log. sin. † 15° 0′		1.41300
add {	log. l = log. sin. ‡ 38° 0′		1.7941
	log. d = log. sin. ‖ 70° 0′		1.9730

Their sum - - - - - - - 1.1801

gives Hld = logarithm of 0.151408, in the natural sines.

And these two numbers (0.267664 and 0.151408) make 0.419072 = A; which, in the table, is the nearest natural sine of 24° 47′ the sun's altitude sought.

The same hour-distance being assumed on the other side of VI, then $LD - Hld$ is 0.116256 the sine of 6° 40′½; which is the sun's altitude at V in the morning, or VII in the evening, when his north declination is 20°.

But when the declination is 20° south (or towards the depressed pole) the difference $Hld - LD$ becomes negative, and thereby shews that, an hour before VI in the morning, or past VI in the evening, the sun's center is 6° 40′½ below the horizon.

EXAMPLE II.

In the same latitude and north declination, from the given altitude to find the hour.

Let the altitude be 48°; and because, in this case, $H = \frac{A - LD}{ld}$, and A (the natural sine of 48°) = .743145, and LD = .267664, A—LD

† The distance of one hour from VI.
‡ The co-latitude of the place.
‖ The co-declination of the sun.

will

will be 0.4754881, whose logarithmic
 sine is - - - - - - - - 1.6771331
from which taking the logarithmic
 sine of $l \times d =$ - - - - - 1.7671354

Remains - - - - - - - - - 1.9099977
the logarithmic sine of the hour-distance sought, viz. of 54° 22′; which, reduced to time, is 3 hours $37\frac{1}{2}$ min. that is, IX h. $37\frac{1}{2}$ min. in the forenoon, or II h. $22\frac{1}{2}$ m. in the afternoon.

Put the altitude = 18°, whose natural sine is .3090170; and thence $A - LD$ will be =.0491953; which divided by $l \times d$, gives .0717179, the sine of 4° $6'\frac{1}{2}$, in time $16\frac{1}{2}$ minutes nearly, before VI in the morning, or after VI in the evening, when the sun's altitude is 18°.

And, if the declination 20° had been towards the south pole, the sun would have been depressed 18° below the horizon at $16\frac{1}{2}$ minutes after VI in the evening; at which time, the twilight would end; which happens about the 22d of November, and 19th of January, in the latitude of 51° $\frac{1}{2}$ north. The same way may the end of twilight, or beginning of dawn, be found for any time of the year.

NOTE 1. If in theorem 2 and 3 (page 361) A is put = 0, and the value of H is computed, we have the hour of sun-rising and setting for any latitude, and time of the year. And if we put $H = 0$, and compute A, we have the sun's altitude or depression at the hour of VI. And lastly, if H, A and D are given, the latitude may be found by the resolution of a quadratic equation; for $l = \sqrt{1 - L^2}$.

NOTE

NOTE 2. When A is equal 0, H is equal $\frac{LD}{ld} = TL \times TD$, the tangent of the latitude multiplied by the tangent of the declination.

As, if it was required, *what is the greatest length of day in latitude* 51° 30′?

To the log. tangent of 51° 30′ 0.0993948
Add the log. tangent of 23° 29′ 1.6379563

Their sum - - - - - - - 1.7373511 is the log. sine of the hour-distance 33° 7′; in time 2 h. 12½ m. The longest day therefore is 12 h. + 4 h. 25 m. = 16 h. 25 m. And the shortest day is 12 h. — 4 h. 25 m. = 7 h. 35 m.

And if the longest day is given, the latitude of the place is found; $\frac{H}{TD}$ being equal to TL. Thus, if the longest day is 13½ hours = 2 × 6 h. + 45 m. and 45 minutes in time being equal to 11¼ degrees.

From the log. sine of 11° 15′ 1.2902357
Take the log. tang. of 23° 29′ 1.6379562

Remains - - - - - - - 1.6522795
= the logarithmic tangent of lat. 24° 11′.

And the same way, the latitudes, where the several geographical *climates* and parallels begin, may be found; and the latitudes of places, that are assigned in authors from the length of their days, may be examined and corrected.

NOTE 3. The same rule for finding the longest day in a given latitude, distinguishes the hour-lines that are necessary to be drawn on any dial from those which would be superfluous.

In lat. 52° 10′ the longest day is 16 h. 32 m. and the hour-lines are to be marked from 44 m. after

after III in the morning, to 16 m. after VIII in the evening.

In the ſame latitude, let the dial of Art. 7. Fig. 4. be propoſed; and the elevation of its ſtile (or the latitude of the place *d*, whoſe horizon is parallel to the plane of the dial) being 15° 9′; the longeſt day at *d*, that is, the longeſt time that the ſun can illuminate the plane of the dial, will (by the rule $H = TL \times TD$) be twice 6 hours 27 minutes = 12 h. 54 m. The difference of longitude of the planes *d* and *Z* was found in the ſame example to be 36° 2′; in time, 2 hours 24 minutes; and the delcination of the plane was from the ſouth towards the weſt. Adding therefore 2 h. 24 m. to 5 h. 33 m. the earlieſt ſun-riſing on a horizontal dial at *d*, the ſum 7 h. 57 m. ſhews that the morning hours, or the parallel dial at *Z*, ought to begin at 3 min. before VIII. And to the lateſt ſun-ſetting at *d*, which is 6 h. 27 m. adding the ſame 2 h. 24 m. the ſum 8 h. 51 m. exceeding 6 h. 16 m. the lateſt ſun-ſetting at *Z*, by 35 m. ſhews that none of the afternoon hour-lines are ſuperfluous. And the 4 h. 13 m. from III. h. 44 m. the ſun-riſing at *Z* to VII h. 57 m. the ſun-riſing at *d*, belong to the other face of the dial; that is, to a dial declining 36° from north to eaſt, and inclining 15°. Fig. 3.

EXAMPLE III.

From the ſame *data* to find the ſun's *azimuth.*

If *H*, *L* and *D* are given, then (by Art. 2. of Rule II.) from *H* having found the altitude and its complement *Z d*; and the arc *P d* (the diſtance

diſtance from the pole) being given; ſay, As the co-ſine of the altitude is to the ſine of the diſtance from the pole, ſo is the ſine of the hour-diſtance from the meridian to the ſine of the azimuth-diſtance from the meridian.

Let the latitude be 51° 30′ north, the declination 15° 9′ ſouth, and the time II h. 24 m. in the afternoon, when the ſun begins to illuminate a vertical wall, and it is required to find the poſition of the wall.

Then, by the foregoing theorems, the complement of the altitude will be 81° 32′½, and *P d* the diſtance from the pole being 109° 5′, and the horary diſtance from the meridian, or the angle *d P Z*, 36°.

To log. ſin. 74° 51′	- -	1.98464
Add log. ſin. 36° 0′	- -	1.76922
And from the ſum	- -	1.75386
Take the log. ſin. 81° 32′½		1.99525
Remains	- - - - -	1.75861 = log.

ſin. 35°, the azimuth diſtance ſouth.

When the altitude is given, find from thence the hour, and proceed as above.

This praxis is of ſingular uſe on many occaſions; in finding the declination of vertical planes more exactly than in the common way, eſpecially if the tranſits of the ſun's center is obſerved by applying a ruler with ſights, either plain or teleſcopical, to the wall or plane, whoſe declination is required.—In drawing a meridian line, and finding the magnetic variation.—In finding the bearings of places in terreſtrial ſurveys; the tranſits of the ſun over any place, or his horizontal diſtance from it being obſerved, together with the altitude and hour.—And thence

tience determining ſmall differences of longitude.—In obſerving the variation at ſea, &c.

The learned Mr. *Andrew Reid* invented an inſtrument ſeveral years ago, for finding the latitude at ſea from two altitudes of the ſun, obſerved on the ſame day, and the interval of the obſervations, meaſured by a common watch. And this inſtrument, whoſe only fault was that of its being ſomewhat expenſive, was made by Mr. *Jackſon*. Tables have been lately computed for that purpoſe.

But we may often, from the foregoing rules, reſolve the ſame problem without much trouble; eſpecially if we ſuppoſe the maſter of the ſhip to know within 2 or 3 degrees what his latitude is. Thus,

Aſſume the two neareſt probable limits of the latitude, and by the theorem $H = \frac{A+LD}{ld}$ compute the hours of obſervation for both ſuppoſitions. If one interval of thoſe computed hours coincides with the interval obſerved, the queſtion is ſolved. If not, the two diſtances of the intervals computed, from the true interval, will give a proportional part to be added to, or ſubtracted from, one of the latitudes aſſumed. And if more exactneſs is required, the operation may be repeated with the latitude already found.

But whichever way the queſtion is ſolved, a proper allowance is to be made for the difference of latitude ariſing from the ſhip's courſe in the time between the two obſervations.

Of

Of the double horizontal dial; and the Babylonia *and* Italian *dials.*

To the *gnomonic* projection, there is sometim added a *stereographic* projection of the hou circles, and the parallels of the sun's declinatio on the same horizontal plane; the upright sid of the gnomon being sloped into an edge, stand ing perpendicularly over the center of the pro jection: so that the dial, being in its due positio the shadow of *that* perpendicular edge is a vert cal circle passing through the sun, in the stereo graphic projection.

The months being duly marked on this dial, th sun's declination, and the length of the day at an time, are had by inspection (as also his altitud by means of a scale of tangents.) But its chie property is, that it may be placed true, wheneve the sun shines, without the help of any other in strument.

Fig. 3. Let *d* be the sun's place in the stereographi projection, *x d y z* the parallel of the sun's decli nation, *Z d* a vertical circle through the sun' center, *P d* the hour-circle; and it is eviden that the diameter *N S* of this projection bein placed duly north and south, these three circle will pass through the point *d*. And therefore to give the dial its due position, we have only t turn its gnomon toward the sun, on a hori zontal plane, until the hour on the commo gnomonic projection coincides with that marke by the hour-circle *P d*, which passes through th intersection of the shadow *Z d* with the circle o the sun's present declination.

The *Babylonian* and *Italian* dials reckon th hours, not from the meridian, as with us, bu

from

from the sun's rising and setting. Thus, in *Italy*, an hour before sun-set is reckoned the 23d hour; two hours before sun-set, the 22d hour; and so of the rest. And the shadow that marks them on the hour-lines, is *that* of the point of a stile. This occasions a perpetual variation between their dials and clocks, which they must correct from time to time, before it arises to any sensible quantity, by setting their clocks so much faster or slower. And in *Italy*, they begin their day, and regulate their clocks, not from sun-set, but from about mid-twilight, when the *Ave Maria* is said; which corrects the difference that would otherwise be between the clock and the dial. Plate XXIII.

The improvements which have been made in all sorts of instruments and machines for measuring time, have rendered such dials of little account. Yet, as the theory of them is ingenious, and they are really, in some respects, the best contrived of any for vulgar use, a general idea of their description may not be unacceptable.

Let Fig. 5. represent an erect direct south wall, on which a *Babylonian dial* is to be drawn, shewing the hours from sun-rising; the latitude of the place, whose horizon is parallel to the wall, being equal to the angle *KCR*. Make, as for a common dial *KG*=*KR* (which is perpendicular to *CR*) the radius of the equinoctial *EQ*, and draw *RS* perpendicular to *CK* for the stile of the dial; the shadow of whose point *R* is to mark the hours, when *SR* is set upright on the plane of the dial.

Then it is evident, that in the contingent line *EQ*, the spaces *K* 1, *K* 2, *K* 3, &c. being taken equal to the tangents of the hour-distances from the meridian, to the radius *KG*, one, two, three, &c. hours after sun-rising, on the equinoctial day; the shadow of the point *R* will be

 found

found, at theſe times, reſpectively in the poi
1, 2, 3, &c.

Draw, for the like hours after ſun-riſing, wh
the ſun is in the tropic of Capricorn ♑ *V*,
like common lines *C D*, *C E*, *C F*, &c. and
theſe hours the ſhadow of the point *R* will
found in thoſe lines reſpectively. Find the ſu
altitudes above the plane of the dial at th
hours, and with their co-tangents *S d*, *S e*, *S*
&c. to radius *S R*, deſcribe arcs interſecting
hour-lines in the points *d*, *e*, *f*, &c. ſo ſhall
right lines 1 *d*, 2 *e*, 3 *f*, &c. be the lines of I,
III, &c. hours after ſun-riſing.

The conſtruction is the ſame in every oth
caſe, due regard being had to the difference
longitude of the place at which the dial wou
be horizontal, and the place for which it is
ſerve. And likewiſe, taking care to draw no li
but what are neceſſary; which may be do
partly by the rules already given for determi
ing the time that the ſun ſhines on any plan
and partly from this, that on the tropical da
the hyperbola deſcribed by the ſhadow of t
point *R*, limits the extent of all the hour-line

The moſt uſeful however, as well as t
ſimpleſt of ſuch dials, is that which is deſcrib
on the two ſides of a meridian plane.

That the *Babylonian* and *Italic* hours are tru
enough marked by right lines, is eaſily ſhew
Mark the three points on a globe, where t
horizon cuts the equinoctial, and the two tropi
toward the eaſt, or weſt; and turn the globe
its axis 15°, or 1 hour; and it is plain, that t
three points which were in a great circle (vi
the horizon) will be in a great circle ſtill; whi
will be projected geometrically into a ſtraig
line. But theſe three points are univerſally t

n's places, one hour after sun-set (or one hour fore sun-rise) on the equinoctial and solstitial ys. The like is true of all other circles of clination, besides the tropics; and therefore, e hours on such dials are truly marked by aight lines limited by the projections of e tropics; and which are rightly drawn, as in e foregoing example.

Note 1. The same dials may be delineated ithout the hour-lines *C D*, *C E*, *C F*, &c. by ting off the sun's azimuths on the plane of the al, from the center *S*, on either side of the sub-ile *C S K*, and the corresponding co-tangents of titude from the same center *S*, for I, II, III, c. hours before or after the sun is in the horizon f the place for which the dial is to serve, on the uinoctial and solstitial days.

2. One of these dials has its name from the urs being reckoned from sun-rising, the be-inning of the *Babylonian* day. But we are not ence to imagine that the *equal* hours, which it ews, were those in which the astronomers of at country marked their observations. These, e know with certainty, were unequal, like the *rwise*, as being twelfth parts of the natural day: d an hour of the night was, in like manner, a elfth part of the night; longer or shorter, cording to the season of the year. So that an ur of the day, and an hour of the night, at the me place, would always make $\frac{1}{12}$ of 24, or 2 uinoctial hours. In *Palestine*, among the *mans*, and in several other countries, 3 of these equal nocturnal hours were a *vigilia* or *watch*. nd the reduction of equal and unequal hours to one another, is extremely easy. If, for in-ance, it is found, by a foregoing rule, that in a rtain latitude, at a given time of the year, the

 length

length of a day is 14 equinoctial hours, th unequal hour is then $\frac{14}{12}$ or $\frac{7}{6}$ of an hour, tha is, 70 minutes; and the nocturnal hour is 5 minutes. The first watch begins at VII (sun set); the second at three times 50 minutes after viz. IX h. 30 m. the third always at midnight the morning watch at $\frac{1}{2}$ hour past II.

If it were required to draw a dial for shewin these unequal hours, or 12th parts of the day we must take as many declinations of the sun a are thought necessary, from the equator toward each tropic: and having computed the sun' altitude and azimuth for $\frac{1}{12}$, $\frac{2}{12}$, $\frac{3}{12}$th parts, &c of each of the diurnal arcs belonging to the de clinations assumed: by these, the several point in the circles of declination, where the shadow of the stile's point falls, are determined: an curve lines drawn through the points of a homologous division will be the hour-lines re quired.

Of the right placing of dials, and having a tru meridian line for the regulating of clocks an watches.

The plane on which the dial is to rest, bein duly prepared, and every thing necessary fo fixing it, you may find the hour tolerably exa by a large equinoctial ring-dial, and set you watch to it. And then the dial may be fixed b the watch at your leisure.

If you would be more exact, take the sun' altitude by a good quadrant, noting the preci time of observation by a clock or watch. Then compute the time for the altitude observed (b the rule, page 362) and set the watch to agre with that time, according to the sun. A *Hadley'*

quadrant

quadrant is very convenient for this purpose; for, by it you may take the angle between the sun and his image, reflected from a bason of water; the half of which angle, subtracting the refraction, is the altitude required. This is best done in summer, and the nearer the sun is to the prime vertical (the east or west azimuth) when the observation is made, so much the better.

Or, in summer, take two equal altitudes of the sun in the same day; one any time between 7 and 10 o'clock in the morning, the other between 2 and 5 in the afternoon; noting the moments of these two observations by a clock or watch: and if the watch shews the observations to be at equal distances from noon, it agrees exactly with the sun; if not, the watch must be corrected by half the difference of the forenoon and afternoon intervals; and then the dial may be set true by the watch.

Thus, for example, suppose you have taken the sun's altitude when it was 20 minutes past VIII in the morning by the watch; and found, by observing in the afternoon, that the sun had the same altitude 10 minutes before IIII; then it is plain, that the watch was 5 minutes too fast for the sun: for 5 minutes after XII is the middle time between VIII h. 20 m. in the morning, and III h. 50 m. in the afternoon; and therefore, to make the watch agree with the sun, it must be set back five minutes.

A good *meridian line*, for regulating clocks or watches, may be had by the following method. *A meridian line.*

Make a round hole, almost a quarter of an inch diameter, in a thin plate of metal; and fix the plate in the top of a south window, in such a

manner, that it may recline from the zenith at an angle equal to the co-latitude of your place, as nearly as you can guess: for then, the plate will face the sun directly at noon on the equinoctial days. Let the sun shine freely through the hole into the room; and hang a plumb-line to the ceiling of the room, at least five or six feet from the window, in such a place as that the sun's rays, transmitted through the hole, may fall upon the line when it is noon by the clock; and having marked the said place on the ceiling, take away the line.

Having adjusted a sliding bar to a dove-tail groove, in a piece of wood about 18 inches long, and fixed a hook into the middle of the bar, nail the wood to the above-mentioned place on the ceiling, parallel to the side of the room in which the window is: the groove and bar being towards the floor. Then, hang the plumb-line upon the hook in the bar, the weight or plummet reaching almost to the floor; and the whole will be prepared for farther and proper adjustment.

This done, find the true solar time by either of the two last methods, and thereby regulate your clock. Then, at the moment of next noon by the clock, when the sun shines, move the sliding-bar in the groove until the shadow of the plumb-line bisects the image of the sun (made by his rays transmitted through the hole) on the floor, wall, or on a white screen placed on the north side of the line; the plummet or weight at the end of the line hanging freely in a pail of water placed below it on the floor.—But because this may not be quite correct for the first time, on account that the plummet will not settle immediately, even in water; it may be farther corrected

rected on the following days, by the above method, with the sun and clock; and so brought to a very great exactness.

N. B. The rays transmitted through the hole, will cast but a faint image of the sun, even on a white screen, unless the room be so darkened that no sun-shine may be allowed to enter, but what comes through the small hole in the plate. And always, for some time before the observation is made, the plummet ought to be immersed in a jar of water, where it may hang freely; by which means the line will soon become steady, which otherwise would be apt to continue swinging.

As this meridian line will not only be sufficient for regulating of clocks and watches to the true time by equation tables, but also for most astronomical purposes, I shall say nothing of the magnificent and expensive meridian lines at *Bologna* and *Rome*, nor of the better methods by which astronomers observe precisely the transits of the heavenly bodies on the meridian.

LECT. XII.

Shewing how to calculate the mean time of any new or full moon, or eclipse, from the creation of the world to the year of CHRIST 5800.

IN the following tables, the mean lunation is about a 20th part of a second of time longer than its measure as now printed in the third edition of my Astronomy; which makes a difference of an hour and 30 minutes in 8000 years.—But this is not material, when only the mean times are required.

PRECEPTS.

To find the mean time of any new or full moon in any given year and month after the Christian Æra.

1. If the given year be found in the third column of the *Table of the moon's mean motion from the sun*, under the title *Years before and after* CHRIST; write out that year, with the mean motions belonging to it, and thereto join the given month with its mean motions. But, if the given year be not in the table, take out the next lesser one to it that you find, in the same column; and thereto add as many *compleat years* as will make up the given year: then, join the given month, and all the respective mean motions.

2. Collect these mean motions into one sum of signs, degrees, minutes, and seconds; remembering, that 60 seconds (″) make a minute, 60 minutes (′) a degree, 30 degrees (°) a sign, and 12 signs (^{s}) a circle. When the signs exceed 12, or 24, or 36 (which are whole circles) reject them, and set down only the remainder; which, together with the odd degrees, minutes, and seconds already set down, must be reckoned the whole sum of the collection.

3. Subtract the result, or sum of this collection, from 12 signs; and write down the remainder. Then, look in the table, under *Days*, for the next less mean motions to this remainder, and

and ſubtract them from it, writing down their remainder.

This done, look in the table under *hours* (marked H.) for the next leſs mean motions to this laſt remainder, and ſubtract them from it, writing down their remainder.

Then, look in the table under *minutes* (marked M.) for the next leſs mean motions to this remainder, and ſubtract them from it, writing down their remainder.

Laſtly, look in the table under *ſeconds* (marked S.) for the next leſs mean motions to this remainder, either greater or leſs; and againſt it you have the ſeconds anſwering thereto.

4. And theſe times collected, will give the mean time of the *required new moon*; which will be right in common years, and alſo in January and February in leap-years; but always one day too late in leap-years after February.

EXAM-

EXAMPLE I.

Required the time of new moon in September, 1764
(a year not inserted in the table.)

		Moon from sun.			
		s	°	′	″
To the year after *Christ's* birth — —	1753	10	9	24	56
Add compleat years -	11	0	10	14	20
(sum 1764)					
And join September - -		2	22	21	8
The sum of these mean motions is		1	12	0	24
Which, being sub. from a circle, or - - - -		12	0	0	0
Leaves remaining - -		10	17	59	36
Next less mean mot. for 26 days, sub. - - - - -		10	16	57	34
And there remains - - -			1	2	2
Next less mean mot. for 2 hours, sub. - - - - -			1	0	57
And the remainder will be - -				1	5
Next less mean mot. for 2 min. sub. - - - - - -				1	1
Remains the mean mot. of 12 sec.					4

These times, being collected, would shew the mean time of the required new moon in September 1764, to be on the 26th day, at 2 hours 2 min. 12 sec. past noon. But, as it is in a leap-year, and after February, the time is one day too late. So, the true mean time is September the 25th, at 2 m. 12 sec. past II in the afternoon.

N. B.

N. B. The tables always begin the day at noon, and reckon thence forward, to the noon of the day following.

To find the mean time of full moon in any given year and month after the Christian Æra.

Having collected the moon's mean motion from the sun for the beginning of the given year and month, and subtracted their sum from 12 signs (as in the former example) add 6 signs to the remainder, and then proceed in all respects as above.

EXAMPLE II.

Required the mean time of full moon in September 1764?

		Moon from sun.			
		s	°	′	″
To the year after *Christ's* birth — —	1753	10	9	24	56
Add compleat years -	11	0	10	14	20
	(sum 1764)				
And join September - -		2	22	21	8
The sum of these mean motions is - - - - - -		1	12	0	24
Which, being subt. from a circle, or - - - -		12	0	0	0
Leaves remaining - - -		10	17	59	36
To which remainder add -		6	0	0	0
And the sum will be - -		4	17	59	36

	Moon from sun.			
	s	°	′	″
Brought over - - - -	4	17	59	36
Next less mean mot. for 11 days, subt. - -	4	14	5	54
And there remains - - -		3	53	42
Next less mean mot. for 7 hours, subt. - -		3	33	20
And the remainder will be -			20	22
Next less mean mot. for 40 min. subt. - - -			20	19
Remains the mean mot. for 8 sec. - - - -				3

So, the mean time, according to the tables, is the 11th of September, at 7 hours 40 minutes 8 seconds past noon. One day too late, being after February in a leap-year.

And thus may the mean time of any new or full moon be found, in any year after the Christian Æra.

To find the mean time of new or full moon in any given year and month before the Christian Æra.

If the given year before the year of CHRIST be found in the third column of the table, under the title *Years before and after* CHRIST, write it out, together with the given month, and join the mean motions. But, if the given year be not in the table, take out the next greater one to it that you find; which being still farther back than the given year, add as many compleat years to it as will bring the time forward to the given year: then join the month, and proceed in all respects as above.

EXAM-

EXAMPLE III.

Required the mean time of new moon in May, the year before Christ 585?

The next greater year in the table is 600, which being 15 years before the given year, add the mean motions for 15 years to those of 600, together with those for the beginning of May.

	Moon from sun.			
	s	o	′	″
To the year before *Christ* 600 -	5	11	6	16
Add compleat years motion 15 -	6	0	55	24
And the mean motions for May	0	22	53	23
The whole sum is - -	0	4	55	3
Which, being subt. from a circle, or - - - -	12	0	0	0
Leaves remaining - -	11	25	4	57
Next less mean mot. for 29 days, subt. - - - - -	11	23	31	54
And there remains - -		1	33	3
Next less mean mot. for 3 hours subt. - - - -		1	31	26
And the remainder will be -			1	37
Next less mean mot. for 3 min. subt. - - - -			1	31
Rem. the mean mot. of 14 seconds - -				6

So,

So, the mean time by the tables, was the 29th of May, at 3 hours 3 min. 14 sec. past noon. A day later than the truth, on account of its being in a leap-year. For as the year of CHRIST 1 was the first after a leap-year, the year 585 before the year 1 was a leap-year, of course.

If the given year be after the Christian Æra, divide its date by 4, and if nothing remains, it is a leap-year in the old stile. But if the given year was before the Christian Æra (or Year of CHRIST 1) subtract one from its date, and divide the remainder by 4; then, if nothing remains, it was a leap-year; otherwise, not.

To find whether the sun is eclipsed at the time of any given change, or the moon at any given full.

Of eclipses. From the *Table of the sun's mean motion* (or distance) *from the moon's ascending node*, collect the mean motions answering to the given time; and if the result shews the sun to be within 18 degrees of either of the nodes at the time of new moon, the sun will be eclipsed at that time. Or, if the result shews the sun to be within 12 degrees of either of the nodes at the time of full moon, the moon will be eclipsed at that time in or near the contrary node: otherwise not.

EXAM-

EXAMPLE IV.

The moon changes on the 26th of September 1764, at 2 h. 2 m. (neglecting the seconds) after noon. (See Example I.) *Qu. Whether the sun will be eclipsed at that time?*

		s	°	′	″
		Sun from node.			
To the year after *Christ's* birth — —	1753	1	28	0	19
Add compleat years -	11	7	2	3	56
	(sum 1764)				
And September - -		8	12	22	49
And 26 days - - -			27	0	13
And 2 hours - -				5	12
And 2 minutes - - -					5
Sun's distance from the ascending node - - -		6	9	32	34

Now, as the descending node is just opposite to the ascending, (viz. 6 signs distant from it) and the tables shew only how far the sun has gone from the ascending node, which, by this example, appears to be 6 signs 9 degrees 32 minutes 34 seconds, it is plain that he must be eclipsed; being then only 9° 32′ 34″ short of the descending node. The time thereof.

EXAM-

EXAMPLE V.

The moon will be full on the 11th *of September* 1764, *at* 7 *h.* 40 *min. past noon.* (See Example II.) *Qu. Whether she will be eclipsed at that time?*

		Sun from node
To the year after *Christ's* birth — —	1753	[illegible]
Add compleat years	11	[illegible]
	(sum 1764)	
And September		[illegible]
And 11 days		[illegible]
And 7 hours		[illegible]
And 40 minutes		[illegible]
Sun's distance from the ascending node		5 24 12 [illegible]

Which being subtracted from 6 signs, leaves only 5° 47′ 32″ remaining; and this being all the space that the sun is short of the descending node, it is plain that the moon must then be eclipsed, because she is just as near the contrary node.

EXAM-

EXAMPLE VI.

Q. Whether the sun was eclipsed in May, the year before CHRIST 585? (See Example III.)

	Sun from node. s	°	′	″
To the year before *Christ* 600 -	9	9	23	51
Add the mean motion of 15 complete years - -	9	19	27	49
And { May - - - -	4	4	37	57
29 days - -	1	0	7	10
3 hours - - -			7	48
3 minutes (neglecting the seconds) - -				8
Sun's distance from the ascending node - -	0	3	44	43

Which being less than 18 degrees, shews that the sun was eclipsed at that time.

This eclipse was foretold by *Thales*, and is thought to be the eclipse which put an end to the war between the Medes and Lydians. *Thales's eclipse.*

The times of the *sun's conjunction with the node*, and consequently the *eclipse months* of any given year, are easily found by the *Table of the sun's mean motion from the moon's ascending node*; much in the same way as the mean conjunctions of the sun and moon are found by the table of the moon's mean motion from the sun. *When eclipses must happen.*

For, collect the sun's mean motion from the node (which is the same as his distance gone from it) for the beginning of any given *year*, and subtract it from 12 signs; then, from the

remainder, subtract the next less mean motio[n] belonging to whatever *month* you find them [in] the table; and from their remainder subtract t[he] next less mean motion for *days*, and so on [for] *hours* and *minutes*: the result of all which [will] shew the time of the sun's mean conjuncti[on] with the *ascending node* of the moon's orbit.

EXAMPLE VII.

Required the time of the sun's conjunction with [the] ascending node in the year 1764?

		Sun from no[de]		
		s	o	
To the year after *Christ's* birth - -	1753	1	28	0
Add compleat years - -	11	7	2	3
Mean dist. at beg. of A. D. 1764		9	0	4
Subtract this distance from a circle, or - - -		12	0	0
And there remains - -		2	29	55
Next less mean motion for March subtract - -		2	1	16
And the remainder will be - -		0	28	39
Next less mean motion for 27 days, subtract - - -		0	28	2
And there remains				36
Next less mean motion for 14 hours, subtracted - -				36
(Remains nearly) the mean motion of 5 minutes - -				

Hen[ce]

Hence it appears, that the sun will pass by the moon's *ascending node* on the 27th of March, 14 hours 5 minutes past noon; viz. on the 28th day, at 5 minutes past II in the morning, according to the tables: but this being in a leap-year, and after February, the time is one day too late. Consequently, the true time is at 5 min. past II in the morning on the 27th day; at which time, the descending node will be directly opposite to the sun.

If 6 signs be added to the remainder arising from the first subtraction, (viz. from 12 signs) and then the work carried on as in the last example, the result will give the mean time of the sun's conjunction with the descending node. Thus, in

EXAMPLE VIII.

Let it be tried to find when the sun will be in conjunction with the descending node *in the year* 1764?

		Sun from node.			
		S	°	′	″
To the year after *Christ's* birth	1753	1	28	0	19
Add compleat years	11	7	2	3	56
M. d. fr. asc. n. at beg. of	1764	9	0	4	15
Subtract this distance from a circle, or		12	0	0	0
And the remainder will be		2	29	55	45
To which add half a circle, or		6	0	0	0
And the sum will be		8	29	55	45

 Next

	Sun fr. node			
	s	°	′	″
Brought over -	8	29	55	4
Next less mean mot. for Sept. subt.	8	12	22	
And there remains -	0	17	32	
Next less mean mot. for 16 days, subt. - - - -	0	16	37	
And the remainder will be -			55	
Next less mean mot. for 21 hours, subtracted - - -			54	
Rem. (nearly) the mean mot. of 31 min. - - -			1	

So that, according to the tables, the sun w
be in conjunction with the *descending node* on t
16th of September, at 21 hours 31 minutes p
noon: one day later than the truth, on accou
of the leap-year.

The limits of *eclipses.*

When the moon changes within 18 days b
fore or after the sun's conjunction with either
the nodes, the sun will be eclipsed at t
change: and when the moon is full within
days before or after the time of the sun's c
junction with either of the nodes, she will
eclipsed at that full: otherwise not.

Their period and restitution.

If to the mean time of any eclipse, either of
sun or moon, we add 557 Julian years 21 d
18 hours 11 minutes and 51 seconds, (in wh
there are exactly 6890 mean lunations) we s
have the mean time of another eclipse. Fo
the end of that time, the moon will be ei
new or full, according as we add it to the ti
of new or full moon; and the sun will be o
45″ farther from the same node, at the end

the said time, than he was at the beginning of it, as appears by the following example *.

The period.		Moon fr. sun. s	°	′	″	Sun fr. node. s	°	′	″
Compleat years	500	3	5	32	47	10	14	45	8
	40	8	26	50	37	1	23	58	49
	17	3	2	21	39	10	28	40	55
days	21	8	16	0	21		21	48	38
hours	18		9	8	35			46	44
minutes	11			5	35				29
seconds	51				26				2
Mean motions		0	0	0	0	0	0	0	45

And this period is so very near, that in 6000 years it will vary no more from the truth, as to the restitution of eclipses, than $8\frac{1}{4}$ minutes of a degree; which may be reckoned next to nothing. It is the shortest in which, after many trials, I can find so near a conjunction of the sun, moon, and the same node.

* Dr. Halley's period of eclipses contains only 18 years 11 days 7 hours 43 minutes 20 seconds; in which time, according to his tables, there are just 223 mean lunations: but, in that time, the sun's mean motion from the node is no more than 11s 29° 31′ 49″, which wants 28′ 11″ of being nearly in conjunction with the same node at the end of the period as it was at the beginning; this period cannot be of constant duration for finding eclipses, because it will in time fall quite without their limits. The following tables make the period 31 seconds shorter, as appears by the following calculation.

The period.		Moon fr. Sun. s	°	′	″	Sun fr. node. s	°	′	″
Compleat years	18	7	11	59	4	11	17	46	18
days	11	4	14	5	54		11	25	29
hours	7		3	33	20			18	11
min.	42			21	20			1	49
sec.	44				22				2
Mean motions		0	0	0	0	11	29	31	49

 This

This table is made by the continual additio[n] of a mean lunation, viz. $29^{d}\ 12^{h}\ 44^{m}\ 3^{s}\ 6^{th}\ 21^{iv}\ 14^{v}\ 24^{vi}\ 0^{vii}$

Lun.		Days.	H.	M.	S.	th.
1	Contain	29	12	44	3	6
2		59	1	28	6	13
3		88	14	12	9	19
4		118	2	56	12	25
5		147	15	40	15	32
6		177	4	24	18	38
7		206	17	8	21	44
8		236	5	52	24	51
9		265	18	36	27	57
10		295	7	20	31	3
20		590	14	41	2	7
30		885	22	1	33	11
40		1181	5	22	4	14
50		1476	12	42	35	18
100		2953	1	25	10	35
200		5906	2	50	21	11
300		8859	4	15	31	46
400		11812	5	40	42	22
500		14765	7	5	52	57
1000		29530	14	11	45	54
2000		59061	4	23	31	48
3000		88591	18	35	17	42
4000		118122	8	47	3	36
5000		147652	22	58	49	30
10000		295305	21	57	39	0
20000		590611	19	55	18	0
30000		885917	17	52	57	0
40000		1181223	15	50	36	0
50000		1476529	13	48	15	0
100000		2953059	3	36	30	0

In 100000 mean lun[a]tions, there are 8085 Juli[an] years 12 days 21 hours [...] minutes 30 seconds: [...] 2953059 days 3 hours 3[6] minutes 30 seconds.

Proof of the Table.

In		Moon from		
		s	°	′
Jul. years	4000	1	14	22
	4000	1	14	22
	80	5	23	41
	5	10	0	18
Days	12	4	26	17
Hours	21		10	40
Min.	36			18
Sec.	30			
M. fr. sun.		0	0	0

Having by the forme[r] precepts computed the mea[n] time of new moon in Ja[nuary], for any given yea[r], it is easy, by this Table, t[o] find the mean time of ne[w] moon in January for an[y] number of years afterward[s], and by means of a sma[ll] table of lunations for 12 [or] 13 months, to make a ge[neral] table for finding th[e] mean time of new or fu[ll] moon in any given year an[d] month whatever.

	D.	H.	M.	S.	Th.
In 11 lunations there are	324	20	4	34	10.
In 12 lunations ———	354	8	48	37	16.
In 13 lunations ———	383	21	32	40	23.

But then it would be best to begin the year with March, t[o] avoid the inconvenience of losing a day by mistake in leap year.

Years of the Julian period.	Years of the World.	Years before and after CHRIST.	Moon from sun. s	°	′	″
706	0	4008	5	28	1	17
714	8	4000	5	9	23	24
1714	1008	3000	11	20	28	57
2714	2008	2000	6	1	34	30
3714	3008	1000	0	12	40	3
3814	3108	900	10	19	46	[illegible]
3914	3208	800	8	26	53	9
4014	3308	700	7	3	59	43
4114	3408	600	5	11	6	16
4214	3508	500	3	18	12	49
4314	3608	400	1	25	19	[illegible]
4414	3708	300	0	2	25	[illegible]
4514	3808	200	10	9	32	29
4614	3908	100	8	16	39	3
4714	4008	1	6	23	45	36
4814	4108	101	5	0	52	9
4914	4208	201	3	7	58	43
5014	4308	301	1	15	5	16
5114	4408	401	11	22	11	49
5214	4508	501	9	29	18	23
5714	5008	1001	1	4	51	9
6414	5708	1701	0	24	37	2
6466	5760	1753	10	9	24	56
6514	5808	1801	6	5	26	15

Before the year of CHRIST. | After CHRIST.

Compleat years.	Moon from sun. s	°	′	″
11	0	10	14	[illegible]
12	5	2	8	[illegible]
13	9	11	40	[illegible]
14	1	21	18	[illegible]
15	6	0	55	24
16	10	22	44	[illegible]
17	3	2	21	[illegible]
18	7	11	59	4
19	11	21	36	[illegible]
20	4	13	25	[illegible]
40	8	26	50	37
60	1	10	15	56
80	5	23	41	15
100	10	7	6	33
200	8	14	13	7
300	6	21	19	40
400	4	28	26	13
500	3	5	32	47
1000	6	11	5	33
2000	0	22	11	[illegible]
3000	7	3	16	39
4000	1	14	22	12

The 4008th year before the year of CHRIST 1, was the 4007th year before the year of his birth; and is supposed to have been the year of the creation.

Julian years, 3 of which have 365 days, and the 4th 366.

Compleat years.	Moon from sun. s	°	′	″
1	4	9	37	24
2	8	19	14	48
3	0	28	52	13
4	5	20	41	4
5	10	0	18	28
6	2	9	55	52
7	6	19	33	17
8	11	11	22	7
9	3	20	59	32
10	8	0	36	55

Months.	Moon from sun. s	°	′	″
Jan.	0	0	0	0
Feb.	0	17	54	48
Mar.	11	29	15	16
April	0	17	10	3
May	0	22	53	25
June	1	10	48	11
July	1	16	31	32
Aug.	2	4	26	20
Sept.	2	22	21	8
Oct.	2	28	4	29
Nov.	3	15	59	17
Dec.	3	21	42	7

This table agrees with the *old stile* until the year 1753; and after that, with the *new*.

Days.	Moon from sun. s	°	′	″	H. M. S.	Moon from sun. ° ′ ″	′ ″ ‴	″ ‴ ⁗	M. S. Th.	Moon from sun. ′ ″ ‴	″ ‴ ⁗	‴ ⁗ ⁗′
1	0	12	11	27	1	0	30	29	31	15	44	47
2	0	24	22	53	2	1	0	57	32	16	15	16
3	1	6	34	20	3	1	31	26	33	16	45	44
4	1	18	45	47	4	2	1	54	34	17	16	13
5	2	0	57	13	5	2	32	23	35	17	46	42
6	2	13	8	40	6	3	2	52	36	18	17	10
7	2	25	20	7	7	3	33	20	37	18	47	39
8	3	7	31	34	8	4	3	49	38	19	18	7
9	3	19	43	0	9	4	34	18	39	19	48	36
10	4	1	54	27	10	5	4	46	40	20	19	5
11	4	14	5	54	11	5	35	15	41	20	49	33
12	4	26	17	20	12	6	5	43	42	21	20	2
13	5	8	28	47	13	6	36	12	43	21	50	31
14	5	20	40	14	14	7	6	41	44	22	20	59
15	6	2	51	40	15	7	37	9	45	22	51	28
16	6	15	3	7	16	8	7	38	46	23	21	56
17	6	27	14	34	17	8	38	6	47	23	52	25
18	7	9	26	0	18	9	8	35	48	24	22	54
19	7	21	37	27	19	9	39	4	49	24	53	22
20	8	3	48	54	20	10	9	32	50	25	23	51
21	8	16	0	21	21	10	40	1	51	25	54	19
22	8	28	11	47	22	11	10	30	52	26	24	48
23	9	10	23	14	23	11	40	58	53	26	55	17
24	9	22	34	41	24	12	11	27	54	27	25	45
25	10	4	46	7	25	12	41	55	55	27	56	14
26	10	16	57	34	26	13	12	24	56	28	26	43
27	10	29	9	1	27	13	42	53	57	28	57	11
28	11	11	20	27	28	14	13	21	58	29	27	40
29	11	23	31	54	29	14	43	50	59	29	58	8
30	0	5	43	21	30	15	14	18	60	30	28	37
31	0	17	54	47								
32	1	0	6	14								

1 Lunation = $29^{d}\ 12^{h}\ 44^{m}\ 3^{s}\ 9^{th}\ 31^{iv}\ 24^{v}\ 24^{vi}\ 0^{vii}$

In leap years, after February, a day and its motion must be added to the time for which the moon's mean distance from the sun is given. But, when the mean time of any new or full moon is required in leap-year after February, a day must be subtracted from the mean time thereof, as found by the tables. In common years they give the day right.

A Table of the Sun's mean Motion from the Moon's Ascending Node.

Years of the Julian period.	Years of the World.	Years before and after CHRIST.		Sun from node. s	°	′	″
706	0	Before the year of Christ.	4008	7	6	17	9
714	8		4000	0	11	4	55
1714	1008		3000	9	10	35	11
2714	2008		2000	6	10	5	28
3714	3008		1000	3	9	35	44
3814	3108		900	7	24	32	46
3914	3208		800	0	9	29	48
4014	3308		700	4	24	26	49
4114	3408		600	9	9	23	51
4214	3508		500	1	24	20	53
4314	3608		400	6	9	17	54
4414	3708		300	10	24	14	56
4514	3808		200	3	9	11	58
4614	3908		100	7	24	8	59
4714	4008	After CHRIST.	1	0	9	6	1
4814	4108		101	4	24	3	3
4914	4208		201	9	9	0	4
5014	4308		301	1	23	57	6
5114	4408		401	6	8	54	8
5214	4508		501	10	23	51	9
5714	5008		1001	9	8	36	18
6414	5708		1701	4	23	15	30
6466	5760		1753	1	28	0	19
6514	5808		1801	8	25	44	44

Compleat years.	Sun from node. s	°	′	″
11	7	2	3	56
12	7	22	11	39
13	8	11	17	2
14	9	0	22	25
15	9	19	27	49
16	10	9	35	31
17	10	28	40	55
18	11	17	46	18
19	0	6	51	43
20	0	26	59	24
40	1	23	58	49
60	2	20	58	13
80	3	17	57	37
100	4	14	57	2
200	8	29	54	3
300	1	14	51	5
400	5	29	48	7
500	10	14	45	8
1000	8	29	30	17
2000	5	29	0	33
3000	2	28	30	50
4000	11	28	1	6

The 4008th year before the year of CHRIST 1, was the 4007th year before the year of his birth; and is supposed to have been the year of the creation.

Compleat years.	Sun from node. s	°	′	″
1	0	19	5	23
2	1	8	10	47
3	1	27	16	10
4	2	17	23	53
5	3	6	29	16
6	3	25	34	40
7	4	14	40	3
8	5	4	47	46
9	5	23	53	9
10	6	12	58	33

Julian years, 3 of which have 365 days, and the 4th 366.

Months.	Sun from node. s	°	′	″
Jan.	0	0	0	0
Feb.	1	2	11	48
March	2	1	16	39
April	3	3	28	27
May	4	4	37	57
June	5	6	49	45
July	6	7	59	14
August	7	9	11	1
Sept.	8	12	22	49
Oct.	9	13	32	18
Nov.	10	15	44	5
Dec.	11	16	53	34

This table agrees with the *old stile* until the year 1753; and after that with the *new*.

Days.	Sun from node.				Sun from node.				Sun from node.			
	s	°	′	″	H. M. S.	° / ′	′ / ″	″ / ‴	M. S. Th.	′ / ″	″ / ‴	‴ / ⁗
1	0	1	2	19								
2	0	2	4	38								
3	0	3	6	57	1	0	2	36	31	1	20	31
4	0	4	9	16	2	0	5	12	32	1	23	7
5	0	5	11	36	3	0	7	48	33	1	25	43
6	0	6	13	54	4	0	10	23	34	1	28	9
7	0	7	16	13	5	0	12	59	35	1	31	55
8	0	8	18	32	6	0	15	35	36	1	33	31
9	0	9	20	51	7	0	18	11	37	1	36	6
10	0	10	23	10	8	0	20	47	38	1	38	42
11	0	11	25	29	9	0	23	23	39	1	41	18
12	0	12	27	48	10	0	25	58	40	1	43	54
13	0	13	30	7	11	0	28	33	41	1	46	36
14	0	14	32	26	12	0	31	9	42	1	49	5
15	0	15	34	15	13	0	33	45	43	1	51	41
16	0	16	37	4	14	0	36	21	44	1	54	17
17	0	17	39	23	15	0	38	57	45	1	56	53
18	0	18	41	41	16	0	41	32	46	1	59	29
19	0	19	44	0	17	0	44	8	47	2	2	5
20	0	20	46	19	18	0	46	44	48	2	4	41
21	0	21	48	38	19	0	49	20	49	2	7	17
22	0	22	50	57	20	0	51	56	50	2	9	53
23	0	23	53	16	21	0	54	32	51	2	11	29
24	0	24	55	35	22	0	57	8	52	2	15	5
25	0	25	57	54	23	0	59	43	53	2	17	41
26	0	27	0	13	24	1	2	19	54	2	20	17
27	0	28	2	32	25	1	4	55	55	2	22	53
28	0	29	4	51	26	1	7	31	56	2	25	29
29	1	0	7	10	27	1	10	7	57	2	28	4
30	1	1	9	29	28	1	12	43	58	2	30	40
31	1	2	11	48	29	1	15	9	59	2	33	16
32	1	3	14	7	30	1	17	55	60	2	35	52

In leap-years, after February, add one day and one day's motion to the time at which the sun's mean distance from the ascending node is required.

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SUPPLEMENT

To Mr. FERGUSON's Book of

LECTURES.

A SUPPLEMENT

TO

Mr. FERGUSON's Book of LECTURES.

On MECHANICS.

The Description of a new and safe Crane, which has four different Powers, adapted to different Weights.

THE common crane consists only of a large wheel and axle; and the rope, by which goods are drawn up from ships, or let down from the quay to them, winds or coils round by the axle, as the axle is turned by men walking in the wheel. But, as these engines have nothing to stop the weight from running down, if any of the men happen to trip or fall in the wheel, the weight descends, and turns the wheel rapidly backward, and tosses the men violently about within it; which has produced melancholy instances, not only of limbs

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broke, but even of lives lost, by this ill-judge
construction of cranes. And besides, they hav
but one power for all sorts of weights; so th
they generally spend as much time in raising
small weight as in raising a great one.

These imperfections and dangers induced m
to think of a method of remedying them. An
for that purpose, I contrived a crane with
proper stop to prevent the danger, and wit
different powers suited to different weights;
that there might be as little loss of time as po
sible: and also, that when heavy goods are l
down into ships, the descent may be regular an
deliberate.

This crane has four different powers: and,
believe, it might be built in a room eight feet
width: the gib being on the outside of th
room.

Three trundles, with different numbers o
staves, are applied to the cogs of a horizontal whee
with an upright axle; and the rope, that draw
up the weight, coils round the axle. Th
wheel has 96 cogs, the largest trundle 24 stave
the next largest has 12, and the smallest has 6
So that, the largest trundle makes 4 revolution
for one revolution of the wheel; the next make
8, and the smallest makes 16. A winch
occasionally put upon the axis of either of the
trundles, for turning it; the trundle being the
used that gives a power best suited to the weight
and the handle of the winch describes a circle i
every revolution equal to twice the circumfe
rence of the axle of the wheel. So that the

lengt

length of the winch doubles the power gained by each trundle.

As the power gained by any machine, or engine whatever, is in direct proportion as the velocity of the power is to the velocity of the weight; the powers of this crane are easily estimated, and they are as follows.

If the winch be put upon the axle of the largest trundle, and turned four times round, the wheel and axle will be turned once round; and the circle described by the power that turns the winch, being, in each revolution, double the circumference of the axle, when the thickness of the rope is added thereto; the power goes through eight times as much space as the weight rises through: and therefore (making some allowance for friction) a man will raise eight times as much weight by the crane as he would by his natural strength without it: the power, in this case, being as eight to one.

If the winch be put upon the axis of the next trundle, the power will be as sixteen to one, because it moves 16 times as fast as the weight moves.

If the winch be put upon the axis of the smallest trundle, and turned round; the power will be as 32 to one.

But, if the weight should be too great, even for this power to raise, the power may be doubled by drawing up the weight by one of the parts of a double rope, going under a pulley in the moveable block, which is hooked to the weight below the arm of the gib; and then the

 power

power will be as 64 to one. That is, a m could then raise 64 times as much weight the crane as he could raise by his natur strength without it; because, for every inc that the weight rises, the working power w move through 64 inches.

By hanging a block with two pullies to t arm of the gib, and having two pullies in t moveable block that rises with the weight, t rope being doubled over and under these pullie the power of the crane will be as 128 to on And so, by increasing the number of pullies, t power may be increased as much as you pleas always remembering, that the larger the pulli are, the less is their friction.

Whilst the weight is drawing up, the ratc teeth of a wheel slip round below a catch or cli that falls successively into them, and so hinde the crane from turning backward, and detai the weight in any part of its ascent, if the m who works at the winch should accidentally ha pen to quit his hold, or choose to rest himse before the weight be quite drawn up.

In order to let down the weight, a man pul down one end of a lever of the second kin which lifts the catch of the ratchet-wheel, a gives the weight liberty to descend. But, if t descent be too quick, he pulls the lever a litt farther down, so as to make it rub against t outer edge of a round wheel; by which mea he lets down the weight as slowly as he pleases and, by pulling a little harder, he may stop t weight, if needful, in any part of its descen

he accidentally quits hold of the lever, the catch immediately falls, and stops both the weight and the whole machine.

This crane is represented in PLATE I. where *A* is the great wheel, and *B* its axle on which the rope *C* winds. This rope goes over a pulley *D* in the end of the arm of the gib *E*, and draws up the weight *F*, as the winch *G* is turned round. *H* is the largest trundle, *I* the next, and *K* is the axis of the smallest trundle, which is supposed to be hid from view by the upright supporter *L*. A trundle *M* is turned by the great wheel, and on the axis of this trundle is fixed the ratchet-wheel *N*, into the teeth of which the catch *O* falls. *P* is the lever, from which goes a rope *QQ*, over a pulley *R* to the catch; one end of the rope being fixed to the lever, and the other end to the catch. *S* is an elastic bar of wood, one end of which is screwed to the floor: and, from the other end goes a rope (out of sight in the figure) to the farther end of the lever, beyond the pin or axis on which it turns in the upright supporter *T*. The use of this bar is to keep up the lever from rubbing against the edge of the wheel *U*, and to let the catch keep in the teeth of the ratchet-wheel: But a weight hung to the farther end of the lever would do full as well as the elastic bar and rope.

When the lever is pulled down, it lifts the catch out of the ratchet-wheel, by means of the rope *QQ*, and gives the weight *F* liberty to descend: but if the lever *P* be pulled a little farther down than what is sufficient to lift the catch *O* out of the ratchet-wheel *N*, it will rub

 against

against the edge of the wheel *U*, and thereb
hinder the too quick descent of the weight; an
will quite stop the weight if pulled hard. An
if the man who pulls the lever, should happe
inadvertently to let it go; the elastic bar wi
suddenly pull it up, and the catch will fall dow
and stop the machine.

WW are two upright rollers, above the axi
or upper gudgeon of the gib *E*: their use is t
let the rope *C* bend upon them, as the gib i
turned to either side, in order to bring the weigh
over the place where it is intended to be l
down.

N. B. The rollers ought to be so placed, th
if the rope *C* be stretched close by their outmo
sides, the half thickness of the rope may b
perpendicularly over the center of the uppe
gudgeon of the gib. For then, and in no othe
position of the rollers, the length of the rop
between the pulley in the gib and the axle o
the great wheel will be always the same, in a
positions of the gib: and the gib will remai
in any position to which it is turned.

When either of the trundles is not turned b
the winch in working the crane, it may be draw
off from the wheel, after the pin near the axis o
the trundle is drawn out, and the thick piece o
wood is raised a little behind the outward sup
porter of the axis of the trundle. But this i
not material: for, as the trundle has no frictio
on its axis but what is occasioned by its weigh
it will be turned by the wheel without any sen
sible resistance in working the crane.

A Pyro

A Pyrometer, that makes the Expansion of Metals by Heat visible to the five and forty thousandth Part of an Inch.

The upper surface of this machine is represented by *Fig.* I. of Plate II. Its frame *ABCD* is made of mohogany wood, on which is a circle divided into 360 equal parts; and within that circle is another, divided into 8 equal parts. If the short bar *E* be pushed one inch forward (or toward the center of the circle) the index *e* will be turned 125 times round the circle of 360 parts or degrees. As 125 times 360 is 45,000, 'tis evident, that if the bar *E* be moved only the 45,000dth part of an inch, the index will move one degree of the circle. But as in my pyrometer, the circle is 9 inches in diameter, the motion of the index is visible to half a degree, which answers to the ninety thousandth part of an inch in the motion or pushing of the short bar *E*.

One end of a long bar of metal *F* is laid into a hollow place in a piece of iron *G*, which is fixed to the frame of the machine; and the other end of this bar is laid against the end of the short bar *E*, over the supporting cross bar *HI*: and, as the end *f* of the long bar is placed close against the end of the short bar, 'tis plain, that if *F* expands, it will push *E* forward, and turn the index *e*.

The machine stands on four short pillars, high enough from a table, to let a spirit-lamp be put on the table under the bar *F*; and when that is done, the heat of the flame of the lamp expands the bar, and turns the index.

There

There are bars of different metals, as silver, brass, and iron; all of the same length as the bar *F*, for trying experiments on the different expansion of different metals, by equal degrees of heat applied to them for equal lengths of time; which may be measured by a pendulum that swings seconds. Thus,

Put on the brass bar *F*, and set the index to the 360th degree: then put the lighted lamp under the bar, and count the number of seconds in which the index goes round the plate, from 360 to 360 again; and then blow out the lamp, and take away the bar.

This done, put on an iron-bar *F* where the brass one was before, and then set the index to the 360th degree again. Light the lamp, and put it under the iron-bar, and let it remain just as many seconds as it did under the brass one; and then blow it out, and you will see how many degrees the index has moved in the circle; and by that means you will know in what proportion the expansion of iron is to the expansion of brass; which I find to be as 210 is to 360, or as 7 is to 12.——By this method, the relative expansion of different metals may be found.

The bars ought to be exactly of equal size; and to have them so, they should be drawn, like wire through a hole.

When the lamp is blown out, you will see the index turn backward; which shews that the metal contracts as it cools.

The inside of this pyrometer is constructed as follows.

In *Fig.* 2. *A a* is the short bar, which moves between rollers; and, on the side *a* it has 15 teeth in an inch, which take into the leaves of a pinion *B* (12 in number) on whose axis is the wheel *C* of 100 teeth, which take into the 10 leaves of the pinion *D*, on whose axis is the wheel *E* of 100 teeth, which take into the 10 leaves of the pinion *F*, on the top of whose axis is the index above-mentioned.

Now, as the wheels *C* and *E* have 100 teeth each, and the pinions *D* and *F* have ten leaves each; 'tis plain, that if the wheel *C* turns once round, the pinion *F* and the index on its axis will turn 100 times round. But, as the first pinion *B* has only 12 leaves, and the bar *A a* that turns it has 15 teeth in an inch, which is 12 and a fourth part more; one inch motion of the bar will cause the last pinion *F* to turn an hundred times round, and a fourth part of an hundred over and above, which is 25. So that, if *A a* be pushed one inch, *F* will be turned 125 times round.

A silk thread *b* is tied to the axis of the pinion *D*, and wound several times round it; and the other end of the thread is tied to a piece of slender watch-spring *G* which is fix'd into the rod *H*. So that, as the bar *f* expands, and pushes the bar *A a* forward, the thread winds round the axle, and draws out the spring; and as the bar contracts, the spring pulls back the thread, and turns the work the contrary way, which pushes back the short bar *A a* against the long bar *f*.—This spring always keeps the teeth of the wheels in contact with the leaves of

 the

the pinions, and so prevents any shake in the teeth.

In *Fig.* 1. the eight divisions of the inner circle are so many thousandth parts of an inch in the expansion or contraction of the bars: which is just one thousandth part of an inch for each division moved over by the index.

A Water-Mill, invented by Dr. Barker, *that has neither Wheel nor Trundle.*

This machine is represented by *Fig.* 1. of Plate III. in which, *A* is a pipe or channel that brings water to the upright tube *B*. The water runs down the tube, and thence into the horizontal trunk *C*, and runs out through holes at *d* and *e* near the ends of the trunk on the contrary sides thereof.

The upright spindle *D* is fixt in the bottom of the trunk, and screwed to it below by the nut *g*; and is fixt into the trunk by two cross bars at *f*: so that, if the tube *B* and trunk be turned round, the spindle *D* will be turned also.

The top of the spindle goes square into the rynd of the upper mill-stone *H*, as in common mills; and, as the trunk, tube, and spindle turn round, the mill-stone is turned round thereby. The lower, or quiescent mill-stone is represented by *I*; and *K* is the floor on which it rests, and wherein is the hole *L* for letting the

mea[l]

meal run through, and fall down into a trough which may be about *M*. The hoop or case that goes round the mill-stone rests on the floor *I*, and supports the hopper, in the common way. The lower end of the spindle turns in a hole in the bridge-tree *G F*, which supports the mill-stone, tube, spindle, and trunk. This tree is moveable on a pin at *b*, and its other end is supported by an iron-rod *N* fixt into it, the top of the rod going through the fixt bracket *O*, and having a screw-nut *o* upon it, above the bracket. By turning this nut forward or backward, the mill-stone is raised or lowered at pleasure.

Whilst the tube *B* is kept full of water from the pipe *A*, and the water continues to run out from the ends of the trunk; the upper mill-stone *H*, together with the trunk, tube, and spindle, turns round. But, if the holes in the trunk were stopt, no motion would ensue; even though the tube and trunk were full of water. For,

If there were no hole in the trunk, the pressure of the water would be equal against all parts of its sides within. But, when the water has free egress through the holes, its pressure there is entirely removed: and the pressure against the parts of the sides which are opposite to the holes, turns the machine.

HYDROSTATICS.

A Machine for demonstrating that, on equal Bo[ttoms], the Pressure of Fluids is in Proportion [to] their perpendicular Heights, without any regar[d] to their Quantities.

THIS is termed *The Hydrostatical Parado[x]* and the machine for shewing it is repr[e]sented in *Fig.* 2. of Plate III. In which, *A* is [a] box that holds about a pound of water, *a b c d* a glass-tube fixt in the top of the box, having [a] small wire within it; one end of the wire bein[g] hooked to the end *F* of the beam of a balanc[e] and the other end of the wire fixt to a moveab[le] bottom, on which the water lies, within th[e] box; the bottom and wire being of equ[al] weight with an empty scale (out of sight in th[e] figure) hanging at the other end of the balanc[e]. If this scale be pulled down, the bottom will b[e] drawn up within the box, and that motion wi[ll] cause the water to rise in the glass-tube.

Put one pound weight into the scale, whic[h] will move the bottom a little, and cause th[e] water to appear just in the lower end of th[e] tube at *a*; which shews that the water presse[s] with the force of one pound on the bottom; pu[t] another pound into the scale, and the water wi[ll] rise from *a* to *b* in the tube, just twice as hig[h] above the bottom as it was when at *a*; and the[n] as its pressure on the bottom supports two poun[d] weight in the scale, 'tis plain that the pressur[e] on the bottom is then equal to two pound[s]. Put a third pound weight in the scale, and th[e]

wate[r]

water will be raiſed from *b* to *c* in the tube, three times as high above the bottom as when it began to appear in the tube at *a*; which ſhews, that the ſame quantity of water that preſſed, but with the force of one pound on the bottom, when raiſed no higher than *a*, preſſes with the force of three pounds on the bottom when raiſed three times as high to *c* in the tube. Put a fourth pound weight into the ſcale, and it will cauſe the water to riſe in the tube from *c* to *d*, four times as high as it was when it was all contained in the box, which ſhews that its preſſure then upon the bottom is four times as great as when it lay all within the box. Put a fifth pound weight into the ſcale, and the water will riſe in the tube from *d* to *e*, five times as high as it was above the bottom before it roſe in the tube; which ſhews that its preſſure on the bottom is then equal to five pounds, ſeeing that it ſupports ſo much weight in the ſcale. And ſo on, if the tube was ſtill longer; for it would ſtill require an additional pound put into the ſcale, to raiſe the water in the tube to an additional height equal to the ſpace *d e*; even if the bore of the tube was ſo ſmall as only to let the wire move freely within it, and leave room for any water to get around the wire.

Hence we infer, that if a long narrow pipe or tube was fixed in the top of a caſk full of liquor, and if as much liquor was poured into the tube as would fill it, even though it were ſo ſmall as not to hold an ounce weight of liquor; the preſſure ariſing from the liquor in the tube would be as great upon the bottom, and

and be in as much danger of bursting it out, as if the cask was continued up, in its full size, to the height of the tube, and filled with liquor.

In order to account for this surprising affair, we must consider that fluids press equally in all manner of directions; and consequently that they press just as strongly upward as they do downward. For, if another tube, as *f*, be put into a hole made into the top of the box, and the box be filled with water; and then, if water be poured in at the top of the tube *abcde*, it will rise in the tube *f* to the same height as it does in the other tube: and if you leave off pouring when the water is at *c*, or any other place in the tube *abcde*, you will find it just as high in the tube *f*: and if you pour in water to fill the first tube, the second will be filled also.

Now it is evident that the water rises in the tube *f*, from the downward pressure of the water in the tube *abcde*, on the surface of the water, contiguous to the inside of the top of the box; and as it will stand at equal heights in both tubes, the upward pressure in the tube *f* is equal to the downward pressure in the other tube. But, if the tube *f* were put in any other part of the top of the box, the rising of the water in it would still be the same: or, if the top was full of holes, and a tube put into each of them, the water would rise as high in each tube as it was poured into the tube *abcde*; and then the moveable bottom would have the weight of the water in all the tubes to bear, besides the weight of all the water in the box.

And seeing that the water is pressed upward into each tube, 'tis evident that, if they be all taken away, excepting the tube *a b c d e*, and the holes in which they stood be stopt up; each part, thus stopt, will be pressed as much upward as was equal to the weight of water in each tube. So that, the upward pressure against the inside of the top of the box, on every part equal in breadth to the width of the tube *a b c d e*, will be pressed upward, with a force equal to the whole weight of water in the tube. And consequently, the whole upward pressure against the top of the box, arising from the weight or downward pressure of the water in the tube, will be equal to the weight of a column of water of the same height with that in the tube, and of the same thickness as the width of the inside of the box; and this upward pressure against the top will re-act downward against the bottom, and be as great thereon, as would be equal to the weight of a column of water as thick as the moveable bottom is broad, and as high as the water stands in the tube. And thus, the paradox is solved.

The moveable bottom has no friction against the inside of the box, nor can any water get between it and the box. The method of making it so, is as follows:

In Fig. 3. *A B C D* represents a section of the box, and *a b b d* is the lid on top thereof, which slides on tight, like the lid of a common paper snuff-box; *E* is the moveable bottom, with a groove around its edge, and in it is put into a bladder *f g*, which is tied close around it in the

groove by a ſtrong waxed thread; the bladd coming up like a purſe within the box, and p over the top of it at *a* and *d* all round, a then the lid preſſed on. So that, if water poured in through the hole *l l* of the lid, it w lie upon the bottom *E*, and be contained in ſpace *f E g b* within the bladder; and the b tom may be raiſed by pulling the wire *i*, wh is fixed to it at *E*: and by thus pulling wire, the water will be lifted up in the tub and as the bottom does not touch againſt inſide of the box, it moves without friction.

Now, ſuppoſe the diameter of this round b tom to be three inches (in which caſe, the a thereof will be 9 circular inches) and the dia ter of the bore of the tube to be a quarter of inch; the whole area of the bottom will be times as great as the area of the top of a that would fill the tube like a cork.

And hence it is plain, that if the move bottom be raiſed only the 144th part of an i the water will thereby be raiſed a whole inc the tube; and conſequently, that if the bot be raiſed one inch, it would raiſe the wate the top of a tube 144 inches, or 12 feet height.

N. B. The box muſt be open below moveable bottom, to let in the air. Ot wiſe, the preſſure of the atmoſphere would ſo great upon the moveable bottom, if it three inches in diameter, as to require pounds in the ſcale, to balance that preſſ before the bottom could begin to move.

A Mac

Machine, to be substituted in Place of the common Hydrostatical Bellows.

In *Fig.* 1. of PLATE IV. *ABCD* is an blong square box, in one end of which is a ound groove, as at *a*, from top to bottom, for eceiving the upright glaſs tube *I*, which is bent a right angle at the lower end (as at *i* in *Fig.* 2.) d to that part is tied the end of a large blader *K*, (Fig. 2.) which lies in the bottom of the ox. Over this bladder is laid the moveable oard *L* (*Fig.* 1. and 2.) in which is fixt an upght wire *M*; and leaden weights, *NN*, to e amount of 16 pounds, with holes in their iddle, are put upon the wire, over the board, d preſs upon it with all their force.

The croſs bar *p* is then put on, to ſecure the be from falling, and keep it in an upright poſion: And then the piece *EFG* is to be put on, e part *G* ſliding tight into the dove-tail'd oove *H*, to keep the weights *NN* horizontal, d the wire *M* upright; there being a round le *e* in the part *EF* for receiving the wire.

There are four upright pins in the four corrs of the box within, each almoſt an inch long, r the board *L* to reſt upon; to keep it from eſſing the ſides of the bladder below it cloſe gether at firſt.

The whole machine being thus put together, ur water into the tube at top; and the ter will run down the tube into the bladder low the board; and after the bladder has been

 filled

filled up to the board, continue pouring water into the tube, and the upward pressure which it will excite in the bladder, will raise the board with all the weight upon it, even though the bore of the tube should be so small, that less than an ounce of water would fill it.

This machine acts upon the same principle, as the one last described, concerning the *Hydrostatical paradox*. For, the upward pressure against every part of the board (which the bladder touches) equal in area to the area of the bore of the tube, will be pressed upward with a force equal to the weight of the water in the tube; and the sum of all these pressures, against so many areas of the board, will be sufficient to raise it with all the weights upon it.

In my opinion, nothing can exceed this simple machine, in making the upward pressure of fluids evident to sight.

The Cause of reciprocating Springs, and of ebbing and flowing Wells, explained.

In *Fig.* 1. of PLATE V. Let *a b c d* be a hill, within which is a large cavern *A A* near the top, filled or fed by rains and melted snow on the top *a*, making their way through chinks and crannies into the said cavern, from which proceeds a small stream *c c* within the body of the hill, and issues out in a spring at *G* on the side of the hill, which will run constantly whilst the cavern is fed with water.

From the same cavern *A A*, let there be a small channel *D*, to carry water into the cavern

B; and from that cavern, let there be a bended channel *E e F*, larger than *D*, joining with the former channel *c c*, as at *f* before it comes to the ſide of the hill: and let the joining at *f* be below the level of the bottom of both theſe caverns.

As the water riſes in the cavern *B*, it will riſe as high in the channel *E e F*: and when it riſes to the top of that channel at *e*, it will run down the part *e F G*, and make a ſwell in the ſpring *G*, which will continue till all the water is drawn off from the cavern *B*, by the natural ſyphon *E e F*, (which carries off the water faſter from *B*, than the channel *D* brings water to it) and then the ſwell will ſtop, and only the ſmall channel *CC* will carry water to the ſpring *G*, till the cavern *B* is filled to *B* again by the rill *D*; and then the water being at the top *e* of the channel *E e F*, that channel will act again as a ſyphon, and carry off all the water from *B* to the ſpring *G*, and ſo make a ſwelling flow of water at *G* as before.

To illuſtrate this by a machine (*Fig.* 2.) let *A* be a large wooden box, filled with water; and let a ſmall pipe *CC* (the upper end of which is fixed into the bottom of the box) carry water from the box to *G*, where it will run off conſtantly, like a ſmall ſpring. Let another ſmall pipe *D* carry water from the ſame box to the box or well *B*, from which let a ſyphon *E e F* proceed, and join with the pipe *CC* at *f*: the bore of the ſyphon being larger than the bore of the feeding pipe *D*. As the water from this pipe riſes in the well *B*, it will alſo riſe as high in the ſyphon *E e F*: and when the ſyphon is

 full

full to the top *e*, the water will run over the bend *e*, down the part *e F*, and go off at the mouth *G*; which will make a great ſtream at *G*: and that ſtream will continue, till the ſyphon has carried off all the water from the well *B*; the ſyphon carrying off the water faſter from *B* than the pipe *D* brings water to it: and then the ſwell at *G* will ceaſe, and only the water from the ſmall pipe *C C* will run off at *G*, till the pipe *D* fills the well *B* again; and then the ſyphon will run, and make a ſwell at *G* as before.

And thus, we have an artificial repreſentation of an ebbing and flowing well, and of a reciprocating ſpring, in a very natural and ſimple manner.

HYDRAULICS.

An Account of the Principles by which Mr. Blake[y] *propoſes to raiſe Water from Mines, or from Rivers to ſupply Towns and Gentlemens Seats, by his new invented Fire-Engine, for which he has received* His MAJESTY's *Patent.*

ALTHOUGH I am not at liberty to deſcribe the whole of this ſimple engine, yet I have the patentee's leave to deſcribe ſuch a one as will ſhew the principles by which it acts.

In *Fig.* 4. of PLATE IV. let *A* be a large ſtrong, cloſe veſſel; immerſed in water up to the cock *b*, and having a hole in the bottom with a valve *a* upon it, opening upward within the veſſel. A pipe *B C* riſes from the bottom

of this vessel, and has a cock *c* in it near the top, which is small there, for playing a very high jet *d*. *E* is the little boiler (not so big as a common tea-kettle) which is connected with the vessel *A* by the steam-pipe *F*; and *G* is a funnel, through which, a little water must be occasionally poured into the boiler, to yield a proper quantity of steam. And a small quantity of water will do for that purpose, because steam possesseth upwards of 14,000 times as much space or bulk as the water does from which it proceeds.

The vessel *A* being immersed in water up to the cock *b*, open that cock, and the water will rush in, through the bottom of the vessel at *a*, and fill it as high up as the water stands on its outside; and the water, coming into the vessel, will drive the air out of it (as high as the water rises within it) through the cock *b*. When the water has done rushing into the vessel, shut the cock *b*, and the valve *a* will fall down, and hinder the water from being pushed out that way, by any force that presseth on its surface. All the part of the vessel above *b*, will be full of common air, when the water rises to *b*.

Shut the cock *c*, and open the cocks *d* and *e*; then pour as much water into the boiler *E* (through the funnel *G*) as will about half fill the boiler; and then shut the cock *d*, and leave the cock *e* open.

This done, make a fire under the boiler *E*, and the heat thereof will raise a steam from the water in the boiler; and the steam will make its way thence, through the pipe *F*, into the

vessel *A*; and the steam will compress the air (above *b*) with a very great force upon the surface of the water in *A*.

When the top of the vessel *A* feels very hot by the steam under it, open the cock *c* in the pipe *C*; and the air being strongly compressed in *A*, between the steam and the water therein, will drive all the water out of the vessel *A*, up the pipe *B C*, from which it will fly up in a jet to a very great height.——In my fountain, which is made in this manner after Mr. Blakey's, three tea-cup-fulls of water in the boiler will afford steam enough to play a jet 30 feet high.

When all the water is out of the vessel *A*, and the compressed air begins to follow the jet, open the cocks *b* and *d* to let the steam out of the boiler *E* and vessel *A*, and shut the cock *c* to prevent any more steam from getting into *A*; and the air will rush into the vessel *A* through the cock *b*, and the water through the valve *a*; and so the vessel will be filled up with water to the cock *b* as before. Then shut the cock *b*, and the cocks *c* and *d*, and open the cock *e*; and then, the next steam that rises in the boiler will make its way into the vessel *A* again; and the operation will go on, as above.

When all the water in the boiler *E* is evaporated, and gone off into steam, pour a little more into the boiler, through the funnel *G*.

In order to make this engine raise water to any gentleman's house; if the house be on the bank of a river, the pipe *B C* may be continued

up

up to the intended height, in the direction *HI*. Or, if the houſe be on the ſide or top of a hill, at a diſtance from the river, the pipe, through which the water is forced up, may be laid along on the hill, from the river or ſpring to the houſe.

The boiler may be fed by a ſmall pipe *K*, from the water that riſes in the main pipe *BCHI*: the pipe *K* being of a very ſmall bore, ſo as to fill the funnel *G* with water in the time that the boiler *E* will require a freſh ſupply. And then, by turning the cock *d*, the water will fall from the funnel into the boiler. The funnel ſhould hold as much water as will about half fill the boiler.

When either of theſe methods of raiſing water, perpendicularly or obliquely, is uſed; there will be no occaſion for having the cock *c* in the main pipe *BCHI*: for ſuch a cock is requiſite only, when the engine is uſed as a fountain.

A contrivance may be very eaſily made, from a lever to the cocks *b*, *d*, and *e*; ſo that, by pulling the lever, the cocks *b* and *d* may be opened when the cock *e* muſt be ſhut; and the cock *e* be opened when *b* and *d* muſt be ſhut.

The boiler *E* ſhould be incloſed in a brick wall, at a little diſtance from it, all around; to give liberty for the flames of the fire under the boiler to aſcend round about it. By which means, (the wall not covering the funnel *G*) the force of the ſteam will be prodigiouſly increaſed by the heat round the boiler; and the funnel and water in it will be heated from the boiler; ſo that, the boiler

boiler will not be chilled by letting cold water into it; and the rising of the steam will be so much the quicker.

Mr. Blakey is the only person who ever thought of making use of air as an intermediate body between steam and water: by which means, the steam is always kept from touching the water, and consequently from being condensed by it. And, on this new principle, he has obtained a patent: so that no one (vary the engine how he will) can make use of air between steam and water, without infringing on the patent, and being subject to the penalties of the law.

This engine may be built for a trifling expence, in comparison of the common fire engine now in use: it will seldom need repairs, and will not consume half so much fuel. And as it has no pumps with pistons, it is clear of all their friction: and the effect is equal to the whole strength or compressive force of the steam; which the effect of the common fire engine never is on account of the great friction of the pistons in their pumps.

ARCHIMEDES's *Screw-Engine for raising Water.*

In *Fig.* 1. of PLATE VI. *ABCD* is a wheel, which is turned round, according to the order of the letters, by the fall of water *E F*, which need not be more than three feet. The axle *G* of the wheel is elevated so, as to make an angle of about 44 degrees with the horizon, and on the top of that axle is a wheel *H* which turns such another wheel *I* of the same number

of teeth: the axle K of this last wheel being parallel to the axle G of the two former wheels.

The axle G is cut into a double threaded screw (as in Fig. 2.) exactly resembling the screw on the axis of the fly of a common jack, which must be (what is called) a right handed screw, like the wood-screws, if the first wheel turns in the direction $ABCD$; but must be a left handed screw, if the stream turns the wheel the contrary way. And, which ever way the screw on the axle G be cut; the screw on the axle K must be cut the contrary way; because these axles turn in contrary directions.

The screws being thus cut, they must be covered close over with boards, like those of a cylindrical cask; and then they will be spiral tubes. Or, they may be made of tubes of stiff leather, and wrapt round the axles in shallow grooves cut therein; as in *Fig.* 3.

The lower end of the axle G turns constantly in the stream that turns the wheel, and the lower ends of the spiral tubes are open into the water. So that, as the wheel and axle are turned round, the water rises in the spiral tubes, and runs out at L, through the holes M, N, as they come about below the axle. These holes (of which there may be any number, as four or six) are in a broad close ring on the top of the axle, into which ring, the water is delivered from the upper open ends of the screw-tubes, and falls into the open box N.

The lower end of the axle K turns on a gudgeon, in the water in N; and the spiral tubes

tubes in that axle take up the water from *N*, and deliver it into such another box under the top of *K*; on which there may be such another wheel as *I*, to turn a third axle by such a wheel upon it.——And in this manner, water may be raised to any given height, when there is a stream sufficient for that purpose to act on the broad float boards of the first wheel.

A quadruple Pump-Mill for raising Water.

This engine is represented in PLATE VII. In which *ABCD* is a wheel, turned by water according to the order of the letters. On the horizontal axis are four small wheels, toothed almost half round: and the parts of their edges on which there are no teeth are cut down so, as to be even with the bottoms of the teeth where they stand.

The teeth of these four wheels take alternately into the teeth of four racks, which hang by two chains over the pullies *Q* and *L*; and to the lower ends of these racks there are four iron rods fixed, which go down into the four forcing pumps, *S*, *R*, *M* and *N*. And, as the wheels turn, the racks and pump-rods are alternately moved up and down.

Thus, suppose the wheel *G* has pulled down the rack *I*, and drawn up the rack *K* by the chain: as the last tooth of *G* just leaves the uppermost tooth of *I*, the first tooth of *H* is ready to take into the lowermost tooth of the rack *K* and pull it down as far as the teeth go; and

and then the rack *I* is pulled upward through the whole ſpace of its teeth, and the wheel *G* is ready to take hold of it, and pull it down again, and ſo draw up the other.——In the ſame manner, the wheels *E* and *F* work the racks *O* and *P*.

Theſe four wheels are fixed on the axle of the great wheel in ſuch a manner, with reſpect to the poſitions of their teeth; that, whilſt they continue turning round, there is never one inſtant of time in which one or other of the pump-rods is not going down, and forcing the water. So that, in this engine, there is no occaſion for having a general air-veſſel to all the pumps, to procure a conſtant ſtream of water flowing from the upper end of the main pipe.

The piſtons of theſe pumps are ſolid plungers, the ſame as deſcribed in the fifth Lecture of my book, to which this is a Supplement. *See* PLATE XI. *Fig.* 4. *of that book, with the deſcription of the figure.*

From each of theſe pumps, near the loweſt end, in the water, there goes off a pipe, with a valve on its fartheſt end from the pump; and theſe ends of the pipes all enter one cloſe box, into which they deliver the water: and into this box, the lower end of the main conduct pipe is fixed. So that, as the water is forced or puſhed into this box, it is alſo puſhed up the main pipe to the height that it is intended to be raiſed.

There is an engine of this ſort, deſcribed in *Ramelli*'s works: but I can truly ſay, that I never

never saw it till some time after I had made thi
model.

The said model is not above twice as big a
the figure of it, here described. I turn it by
winch fixed on the gudgeon of the axle behin
the water wheel; and, when it was newly made
and the pistons and valves in good order, I pu
tin pipes 15 feet high upon it, when they were
joined together, to see what it could do. An
I found, that in turning it moderately by th
winch, it would raise a hogshead of water in a
hour, to the height of 15 feet.

DIALLING.

The universal Dialling Cylinder.

IN *Fig.* 1. of PLATE VIII. *ABCD* re
presents a cylindrical glass tube, closed a
both ends with brass plates, and having a wire o
axis *EFG* fixt in the centers of the brass plate
at top and bottom. This tube is fixed to a ho
rizontal board *H*, and its axis makes an angl
with the board equal to the angle of the earth's axi
with the horizon of any given place, for whic
the cylinder is to serve as a dial. And it mu
be set with its axis parallel to the axis of th
world in that place; the end *E* pointing to th
elevated pole. Or, it may be made to mov
upon a joint; and then it may be elevated fo
any particular latitude.

There are 24 straight lines, drawn with a dia
mond, on the outside of the glass, equidistan
from each other, and all of them parallel to th
axis. These are the hour-lines; and the hour
ar

are set to them as in the figure: the XII next *B* stands for midnight, and the opposite XII, next the board *H*, stands for mid-day or noon.

The axis being elevated to the latitude of the place, and the foot-board set truly level, with the black line along its middle in the plane of the meridian, and the end *N* toward the north; the axis *E F G* will serve as a stile or gnomon, and cast a shadow on the hour of the day, among the parallel hour lines when the sun shines on the machine. For, as the sun's apparent diurnal motion is equable in the heavens, the shadow of the axis will move equably in the tube; and will always fall upon *that* hour-line which is opposite to the sun, at any given time.

The brass plate *AD*, at the top, is parallel to the equator, and the axis *EFG* is perpendicular to it. If right lines be drawn from the center of this plate, to the upper ends of the equidistant parallel lines on the outside of the tube; these right lines will be the hour-lines on the equinoctial dial *AD*, at 15 degrees distance from each other: and the hour-letters may be set to them as in the figure. Then, as the shadow of the axis within the tube comes on the hour-lines of the tube, it will cover the like hour-lines on the equinoctial plate *AD*.

If a thin horizontal plate *ef* be put within the tube, so as its edge may touch the tube all around; and right lines be drawn from the center of that plate to those points of its edge which are cut by the parallel hour-lines on the tube; these right lines will be the hour-lines of a horizontal dial, for the latitude to which the tube is elevated.

vated. For, as the ſhadow of the axis come ſucceſſively to the hour-lines of the tube, an covers them, it will then cover the like hour lines on the horizontal plate ef, to which th hours may be ſet; as in the figure.

If a thin vertical plate gC, be put within th tube, ſo as to front the meridian or 12 o'cloc line thereof, and the edge of this plate touc the tube all around; and then, if right lines b drawn from the center of the plate to thoſe point of its edge which are cut by the parallel hour lines on the tube; theſe right lines will be hour lines of a vertical ſouth dial: and the ſhadow o the axis will cover them at the ſame times whe it covers thoſe of the tube.

If a thin plate be put within the tube ſo, as t decline, or incline, or recline, by any given num ber of degrees; and right lines be drawn from its center to the hour-lines of the tube; theſe righ lines will be the hour-lines of a declining, inclin ing, or reclining dial, anſwering to the like num ber of degrees, for the latitude to which the tub is elevated.

And thus, by this ſimple machine, all th principles of dialling are made very plain, and evident to the ſight. And the axis of the tube (which is parallel to the axis of the world in every latitude to which it is elevated) is the ſtile or gnomon for all the different kinds of ſun-dials.

And laſtly, if the axis of the tube be drawn out, with the plates AD, ef, and gC upon it and ſet it up in ſun-ſhine, in the ſame poſition as they were in the tube; you will have an equi- noctial

ctial dial *AD*, a horizontal dial *ef*, and a verti-
l south dial *gC*; on all which, the time of the
y will be shewn by the shadow of the axis or
omon *EFG*.

Let us now suppose that, instead of a glass
be, *ABCD* is a cylinder of wood; on which
e 24 parallel hour-lines are drawn all around,
equal distances from each other; and that,
om the points at top, where these lines end,
ght lines are drawn toward the center, on the
t surface *AD*: These right lines will be the
our-lines on an equinoctial dial, for the latitude
f the place to which the cylinder is elevated
bove the horizontal foot or pedestal *H*; and
hey are equidistant from each other, as in *Fig*. 2.
hich is a full view of the flat surface or top
D of the cylinder, seen obliquely in *Fig*. 1.
nd the axis of the cylinder (which is a straight
ire *EFG* all down its middle) is the stile or
nomon; which is perpendicular to the plane of
e equinoctial dial, as the earth's axis is per-
endicular to the plane of the equator.

To make a horizontal dial, by the cylinder,
or any latitude to which its axis is elevated;
raw out the axis and cut the cylinder quite
hrough, as at *ebfg*, parallel to the horizontal
oard *H*, and take off the top part *eADfe*; and
e section *ebfge* will be of an elliptical form,
s in *Fig*. 3. Then, from the points of this
ection (on the remaining part *eBCf*) where
he parallel lines on the outside of the cylinder
eet it, draw right lines to the center of the
ection; and they will be the true hour lines for
horizontal dial, as *abcda* in *Fig*. 3. which may
e included in a circle drawn on that section.

Then put the wire into its place again, and will be a ſtile for caſting a ſhadow on the ti of the day, on that dial. So, E (Fig. 3.) is t ſtile of the horizontal dial, parallel to the axis the cylinder.

To make a vertical ſouth dial by the cyli der, draw out the axis, and cut the cylind perpendicularly to the horizontal board H, as $g\,i\,C\,k\,g$, beginning at the hour line ($B\,g\,e\,A$) XII. and making the ſection at right angles the line $S\,H\,N$ on the horizontal board. The take off the upper part $g\,A\,D\,C$, and the face the ſection thereon will be elliptical, as ſhewn *Fig.* 4. From the points in the edge of t ſection, where the parallel hour lines on the rou ſurface of the cylinder meet it, draw right lin to the center of the ſection; and they will the true hour lines on a vertical direct ſouth di for the latitude to which the cylinder was e vated: and will appear as in *Fig.* 4. on whi the vertical dial may be made of a circular ſhap or of a ſquare ſhape as repreſented in the figur And F will be its ſtile parallel to the axis of t cylinder.

And thus, by cutting the cylinder any wa ſo as its ſection may either incline, or decline, recline, by any given number of degrees; a from thoſe points in the edge of the ſecti where the outſide parallel hour lines meet draw right lines to the center of the ſection; a they will be the true hour lines, for the like d clining, reclining, or inclining dial: And t axis of the cylinder will always be the gnom or ſtile of the dial. For, whichever way t plane of the dial lies, its ſtile (or the edge there th

that casts the shadow on the hours of the day) must be parallel to the earth's axis, and point toward the elevated pole of the heavens.

To delineate a Sun-Dial on Paper; which when pasted round a Cylinder of Wood shall shew the Time of the Day, the Sun's Place in the Ecliptic and his Altitude, at any Time of Observation. See PLATE IX.

Draw the right line *a A B*, parallel to the top of the paper; and, with any convenient opening of the compasses, set one foot in the end of the line at *a*, as a center, and with the other foot describe the quadrantal arc *A E*, and divide it into 90 equal parts or degrees. Draw the right line *AC*, at right angles to *a A B*, and touching the quadrant *AE* at the point *A*. Then, from the center *a*, draw right lines through as many degrees of the quadrant, as are equal to the sun's altitude at noon, on the longest day of the year, at the place for which the dial is to serve; which altitude, at London, is 62 degrees: and continue these right lines till they meet the tangent line *AC*; and, from these points of meeting, draw straight lines across the paper, parallel to the first right line *A B*, and they will be the parallels of the sun's altitude, in whole degrees, from sun-rise till sun-set, on all the days of the year.—These parallels of altitude must be drawn out to the right line *B D*, which must be parallel to *AC*, and as far as is equal to the intended circumference of the cylinder on which the paper is to be pasted, when the dial is drawn upon it.

Divide the space between the right lines *AC* and *B D* (at top and bottom) into twelve equal

parts, for the twelve ſigns of the ecliptic; an
from mark to mark, of theſe diviſions at t
and bottom, draw right lines parallel to AC a
BD; and place the characters of the 12 ſigns
theſe twelve ſpaces, at the bottom, as in the figur
beginning with ♑ or Capricorn, and endi
with ♓ or Piſces. The ſpaces including t
ſigns ſhould be divided by parallel lines i
halves; and if the breadth will admit of
without confuſion, into quarters alſo.

At the top of the dial, make a ſcale of t
months and days of the year, ſo as the days m
ſtand over the ſun's place for each of them
the ſigns of the ecliptic. The ſun's place,
every day of the year, may be found by a
common ephemeris: and here it will be beſt
make uſe of an ephemeris for the ſecond y
after leap year; as the neareſt mean for the ſu
place on the days of the leap year, and on th
of the firſt, ſecond, and third year after.

Compute the ſun's altitude for every hour
the latitude of your place) when he is in
beginning, middle, and end of each ſign of
ecliptic; his altitude at the end of each ſ
being the ſame as at the beginning of the n
And, in the upright parallel lines, at the beg
ning and middle of each ſign, make marks
theſe computed altitudes among the horizo
parallels of altitude, reckoning them downwa
according to the order of the numeral figures
to them at the right hand, anſwering to the
diviſions of the quadrant at the left. A
through theſe marks, draw the curve hour-li
and ſet the hours to them, as in the fig
reckoning the forenoon hours downward,

he afternoon hours upward.——The ſun's altiude ſhould alſo be computed for the half hours; nd the quarter lines may be drawn, very nearly n their proper places, by eſtimation and accuacy of the eye. Then, cut off the paper at the ft hand, on which the quadrant was drawn, loſe by the right line *AC*, and all the paper at he right hand cloſe by the right line *BD*; and ut it alſo cloſe by the top and bottom horizontal ines; and it will be fit for paſting round the ylinder.

This cylinder is repreſented in miniature by *Fig.* 1. PLATE X. It ſhould be hollow, to old the ſtile *DE* when it is not uſed. The rooked end of the ſtile is put into a hole in the op *AD* of the cylinder; and the top goes on ightiſh, but muſt be made to turn round on the ylinder, like the lid of a paper ſnuff-box. The ile muſt ſtand ſtraight out, perpendicular to the de of the cylinder, juſt over the right line *AB* n PLATE IX, where the parallels of the ſun's ltitude begin: and the length of the ſtile, or iſtance of its point *e* from the cylinder, muſt be qual to the radius *aA* of the quadrant *AE* in LATE IX.

The method of uſing this dial is as follows.

Place the horizontal foot *BC* of the cylinder n a level table where the ſun ſhines, and turn the op *AD* till the ſtile ſtands juſt over the day of he then preſent month. Then turn the cylinder about, on the table, till the ſhadow of the ile falls upon it, parallel to theſe upright lines hich divide the ſigns; that is, till the ſhadow e parallel to a ſuppoſed axis in the middle of he cylinder: and then, the point, or loweſt end

 of

of the ſhadow, will fall upon the time of th day, as it is before or after noon, among the curv hour-lines; and will ſhew the ſun's altitude a that time, among the croſs parallels of his alti tude, which go round the cylinder: and, at th ſame time, it will ſhew in what ſign of the eclip tic the ſun then is, and you may very nearl gueſs at the degree of the ſign, by eſtimation o the eye.

The ninth plate, on which this dial is drawn may be cut out of the book, and paſted round cylinder whoſe length is 6 inches and 6 tenth of an inch below the moveable top; and it diameter 2 inches and 24 hundred parts of a inch——Or, I ſuppoſe the copper-plate print of it may be had at Mr. *Cadell*'s, bookſeller i the Strand, London. But it will only do fo London, and other places of the ſame latitude.

When a level table cannot be had, the dial ma be hung by the ring *F* at the top. And when i is not uſed, the wire that ſerves for a ſtile ma be drawn out, and put up within the cylinder and the machine carried in the pocket.

To make three Sun-Dials upon three different Planes ſo as they may all ſhew the Time of the Day b one Gnomon.

On the flat board *ABC*, deſcribe a horizonta dial, according to any of the rules laid down i the Lecture on Dialling; and to it fix its gnomo *FGH*, the edge of the ſhadow from the ſid *FG* being that which ſhews the time of th day.

To this horizontal or flat board, join th upright board *EDC*, touching the edge *GH* o the gnomon. Then, making the top of th gnomon

gnomon at H the center of the vertical south dial, describe a south dial on the board EDC.

Lastly, on a circular plate IK describe an equinoctial dial, all the hours of which dial are equidistant from each other: and making a slit cd in that dial, from its edge to its center, in the XII o'clock line; put the said dial perpendicularly on the gnomon FG, as far as the slit will admit of; and the triple dial will be finished; the same gnomon serving all the three, and shewing the same time of the day on each of them.

An universal Dial on a plain Cross.

This dial is represented by *Fig.* 1. of PLATE XI, and is moveable on a joint C, for elevating it to any given latitude, on the quadrant $C\,o\,90$, as it stands upon the horizontal board A. The arms of the cross stands at right angles to the middle part; and the top of it, from a to n, is of equal length with either of the arms ne or mk.

Having set the middle line tu to the latitude of your place, on the quadrant, the board A level, and the point N northward by the needle; the plane of the cross will be parallel to the plane of the equator; and the machine will be rectified.

Then, from III o'clock in the morning, till VI; the upper edge kl of the arm io will cast a shadow on the time of the day on the side of the arm cm: from VI till IX, the lower edge i of the arm io will cast a shadow on the hours on the side oq. From IX in the morning to XII at noon, the edge ab of the top part an will cast a shadow on the hours on the arm nef: from XII to III in the afternoon, the edge cd of the top

 part

part will cast a shadow on the hours on the arm klm: from III to VI in the evening the edge gh will cast a shadow on the hours on the part pq; and from VI till IX, the shadow of the edge ef will shew the time on the top part an.

The breadth of each part, ab, ef, &c. must be so great as never to let the shadow fall quite without the part or arm on which the hours are marked, when the sun is at his greatest declination from the equator.

To determine the breadth of the sides of the arms which contain the hours, so as to be in just proportion to their length; make an angle ABC (Fig. 2.) of $23\frac{1}{2}$ degrees, which is equal to the sun's greatest declination: and suppose the length of each arm, from the side of the long middle part, and also the length of the top-part above the arms, to be equal to Bd.

Then, as the edges of the shadow, from each of the arms, will be parallel to Be, making an angle of $23\frac{1}{2}$ degrees with the side Bd of the arm when the sun's declination is $23\frac{1}{2}$ degrees; 'tis plain, that if the length of the arm be Bd, the least breadth that it can have, to keep the edge Be of the shadow $Begd$ from going off the side of the arm de before it comes to the end ed thereof, must be equal to ed or dB. But in order to keep the shadow within the quarter divisions of the hours, when it comes near the end of the arm, the breadth thereof should be still greater, so as to be almost doubled, on account of the distance between the tips of the arms.

To

To place the hours right on the arms, take the following method.

Lay down the croſs *acbd* (*Fig.* 3.) on a ſheet of paper; and with a black lead pencil, held cloſe to it, draw its ſhape and ſize on the paper. Then taking the length *ae* in your compaſſes, and ſetting one foot in the corner *A*, with the other foot deſcribe the quadrantal arc *ef*.—— Divide this arc into ſix equal parts, and through the diviſion-marks draw right lines *ag*, *ah*, &c. continuing three of them to the arm *ce*, which are all that can fall upon it; and they will meet the arm in theſe points through which the lines that divide the hours from each other (as in *Fig.* 1.) are to be drawn right acroſs it.

Divide each arm, for the three hours it contains, in the ſame manner; and ſet the hours to their proper places (on the ſides of the arms) as they are marked in Fig. 3. Each of the hour ſpaces ſhould be divided into four equal parts, for the half hours and quarters, in the quadrant *ef*; and right lines ſhould be drawn through theſe diviſion-marks in the quadrant, to the arms of the croſs; in order to determine the places thereon where the ſub-diviſions of the hours muſt be marked.

This is a very ſimple kind of univerſal dial; it is very eaſily made, and will have a pretty uncommon appearance in a garden.——I have ſeen a dial of this ſort, but never ſaw one of the kind that follows.

An

An universal Dial, ſhewing the Hours of the Day by a terreſtrial Globe, and by the Shadows of ſeveral Gnomons, at the ſame Time: together with all the Places of the Earth which are then enlightened by the Sun; and thoſe to which the Sun is then riſing, or on the Meridian, or Setting.

This dial (*See* PLATE XII.) is made of a thick ſquare piece of wood, or hollow metal. The ſides are cut into ſemicircular hollows, in which the hours are placed; the ſtile of each hollow coming out from the bottom thereof, as far as the ends of the hollows project. The corners are cut out into angles, in the inſides of which, the hours are alſo marked; and the edge of the end of each ſide of the angle ſerves as a ſtile for caſting a ſhadow on the hours marked on the other ſide.

In the middle of the uppermoſt ſide or plane, there is an equinoctial dial; in the center whereof, an upright wire is fixt for caſting a ſhadow on the hours of that dial, and ſupporting a ſmall terreſtrial globe on its top.

The whole dial ſtands on a pillar, in the middle of a round horizontal board, in which there is a compaſs and magnetic needle, for placing the *meridian* ſtile toward the ſouth. The pillar has a joint with a quadrant upon it, divided into 90 degrees (ſuppoſed to be hid from ſight under the dial in the figure) for ſetting it to the latitude of any given place; the ſame way as already deſcribed in the dial on the croſs.

The equator of the globe is divided into 24 equal parts, and the hours are laid down upon it

at

at these parts. The time of the day may be known by these hours, when the sun shines upon the globe.

To rectify and use this dial, set it on a level table, or sole of a window, where the sun shines, placing the meridian stile due south, by means of the needle; which will be, when the needle points as far from the north fleur-de-lis toward the west, as it declines westward, at your place. Then bend the pillar in the joint, till the black line on the pillar comes to the latitude of your place in the quadrant.

The machine being thus rectified, the plane of its dial-part will be parallel to the equator, the wire or axis that supports the globe will be parallel to the earth's axis, and the north pole of the globe will point toward the north pole of the heavens.

The same hour will then be shewn in several of the hollows, by the ends of the shadows of their respective stiles: The axis of the globe will cast a shadow on the same hour of the day, in the equinoctial dial, in the center of which it is placed, from the 20th of March to the 23d of September; and, if the meridian of your place on the globe be set even with the meridian stile, all the parts of the globe that the sun shines upon, will answer to those places of the real earth which are then enlightened by the sun. The places where the shade is just coming upon the globe, answer to all those places of the earth to which the sun is then setting; as the places where it is going off, and the light coming on, answer to all the places of the earth where the sun is

is then rising. And lastly, if the hour of VI be marked on the equator in the meridian of your place (as it is marked on the meridian of London in the figure) the division of the light and shade on the globe will shew the time of the day.

The northern stile of the dial (opposite to the southern or meridian one) is hid from sight in the figure, by the axis of the globe. The hours in the hollow to which that stile belongs, are also supposed to be hid by the oblique view of the figure: but they are the same as the hours in the front-hollow. Those also in the right and left hand semicircular hollows are mostly hid from sight; and so also are all those on the sides next the eye of the four acute angles.

The construction of this dial is as follows. See PLATE XIII.

On a thick square piece of wood, or metal, draw the lines *a c* and *b d*, as far from each other as you intend for the thickness of the stile *abcd*; and in the same manner, draw the like thickness of the other three stiles, *efgh*, *iklm*, and *nopq*, all standing outright as from the center.

With any convenient opening of the compasses, as *aA* (so as to leave proper strength of stuff when *KI* is equal to *aA*) set one foot in *a*, as a center, and with the other foot describe the quadrantal arc *Ac*. Then without altering the compasses, set one foot in *b* as a center, and with the other foot describe the quadrant *dB*. All the other quadrants in the figure must be described in the same manner, and with the

the ſame opening of the compaſſes, on their centers *e*, *f*; *i*, *k*; and *n*, *o*: and each quadrant divided into 6 equal parts, for ſo many hours, as in the figure; each of which parts muſt be ſub-divided into 4, for the half hours and quarters.

At equal diſtances from each corner, draw the right lines *Ip* and *Kp*, *Lq* and *Mq*, *Nr* and *Or*, *Ps* and *Qs*; to form the four angular hollows *IpK*, *LqM*, *NrO*, and *PsQ*; making the diſtances between the tips of theſe hollows, as *IK*, *LM*, *NO*, and *PQ*, each equal to the radius of the quadrants; and leaving ſufficient room within the angular points, *p*, *q*, *r*, and *s*, for the equinoctial in the middle.

To divide the inſides of theſe angles properly, for the hour-ſpaces thereon; take the following method.

Set one foot of the compaſſes in the point *I*, as a center; and open the other to *K*, and with that opening, deſcribe the arc *Kt*: then, without altering the compaſſes, ſet one foot in *K*, and with the other foot deſcribe the arc *It*. Divide each of theſe arcs, from *I* and *K* to their interſection at *t*, into four equal parts; and from their centers *I* and *K*, through the points of diviſion, draw the right lines *I*3, *I*4, *I*5, *I*6, *I*7; and *K*2, *K*1, *K*12, *K*11; and they will meet the ſides *Kp* and *Ip* of the angle *IpK* where the hours thereon muſt be placed. And theſe hour-ſpaces in the arcs muſt be ſubdivided into four equal parts, for the half hours and quarters.——Do the like for the other three angles, and draw the dotted lines, and ſet the hours

hours in the insides where those lines meet them, as in the figure: and the like hour-lines will be parallel to each other in all the quadrants and in all the angles.

Mark points for all these hours, on the upper side; and cut out all the angular hollows, and the quadrantal ones quite through the places where their four gnomons must stand; and lay down the hours on their insides, as in PLATE XII, and then set in their four gnomons, which must be as broad as the dial is thick; and this breadth and thickness must be large enough to keep the shadows of the gnomons from ever falling quite out at the sides of the hollows, even when the sun's declination is at the greatest.

Lastly, draw the equinoctial dial in the middle, all the hours of which are equidistant from each other: and the dial will be finished.

As the sun goes round, the broad end of the shadow of the stile *a b c d* will shew the hours in the quadrant *A c*, from sun-rise till VI in the morning; the shadow from the end *M* will shew the hours on the side *L q* from V to IX in the morning; the shadow of the stile *e f g b* in the quadrant *D g* (in the long days) will shew the hours from sun-rise till VI in the morning; and the shadow of the end *N* will shew the morning hours, on the side *O r*, from III to VII.

Just as the shadow of the northern stile *a b c d* goes off the quadrant *A c*, the shadow of the southern stile *i k l m* begins to fall within the quadrant *F l*, at VI in the morning; and shews the time, in that quadrant, from VI till XII at noon;

noon; and from noon till VI in the evening in the quadrant *m E*. And the ſhadow of the end *O*, ſhews the time from XI in the forenoon till III in the afternoon, on the ſide *r N*; as the ſhadow of the end *P* ſhews the time from IX in the morning till I o'clock in the afternoon, on the ſide *Q s*.

At noon, when the ſhadow of the eaſtern ſtile *e f g h* goes off the quadrant *b C* (in which it ſhewed the time from VI in the morning till noon, as it did in the quadrant *g D* from ſun-riſe till VI in the morning) the ſhadow of the weſtern ſtile *n o p q* begins to enter the quadrant *H p*; and ſhews the hours thereon from XII at noon till VI in the evening; and after *that* till ſun-ſet, in the quadrant *q G*: and the end *Q* caſts a ſhadow on the ſide *P s* from V in the evening till IX at night, if the ſun be not ſet before that time.

The ſhadow of the end *I* ſhews the time on the ſide *K p* from III till VII in the afternoon; and the ſhadow of the ſtile *a b c d* ſhews the time from VI in the evening till the ſun ſets.

The ſhadow of the upright central wire, that ſupports the globe at top, ſhews the time of the day, in the middle or equinoctial dial, all the ſummer half year, when the ſun is on the north ſide of the equator.

In this ſupplement to my book of Lectures, all the machines that I have added to my apparatus, ſince that book was printed, are deſcribed, excepting two; one of which is a model of

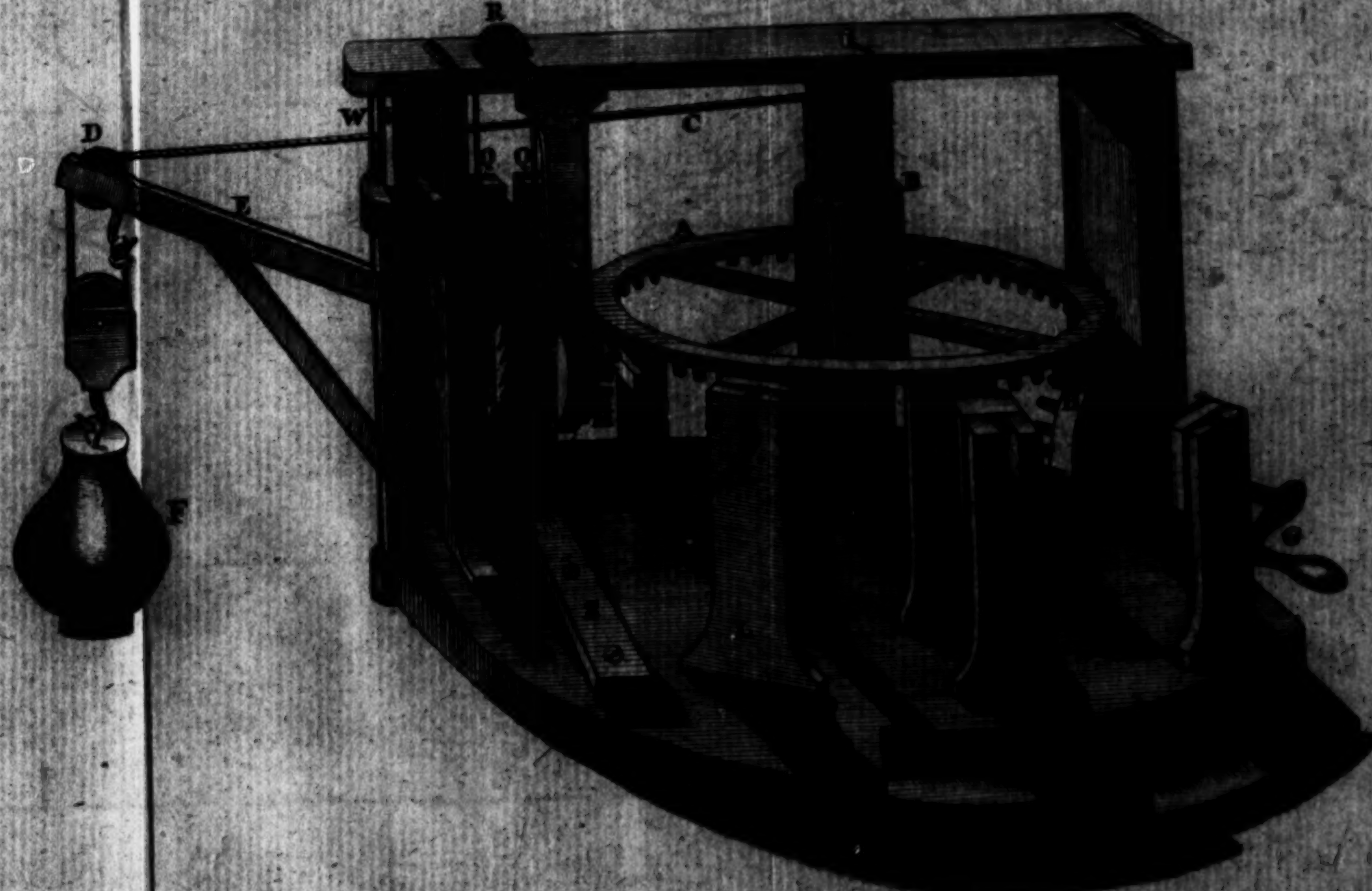
of a mill for sawing timber, and the other is a model of the great engine at London-bridge, for raising water. And my reasons for leaving them out are as follow.

First, I found it impossible to make such a drawing of the saw-mill as could be understood; because, in whatever view it be taken, a great many parts of it hide others from sight. And, in order to shew it in my Lectures, I am obliged to turn it into all manner of positions.

Secondly, because any person who looks on *Fig.* 1. of Plate XII in the book, and reads the account of it in the fifth lecture therein, will be able to form a very good idea of the London-bridge-engine, which has only two wheels and two trundles more than there are in Mr. *Aldersea's* engine, from which the said figure was taken.

FINIS.

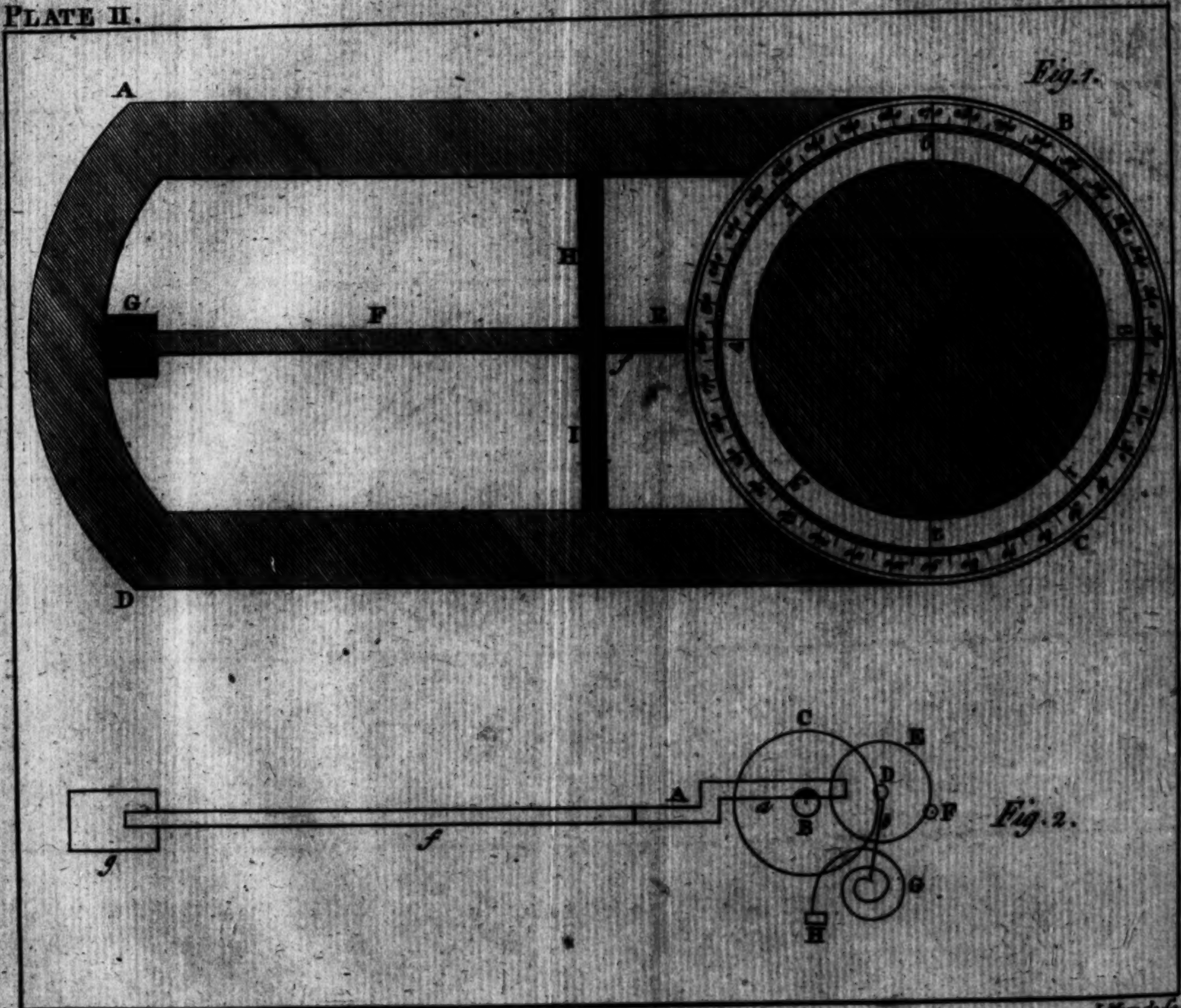
PLATE I.



J. Ferguson delin.

J. Hynde sc.

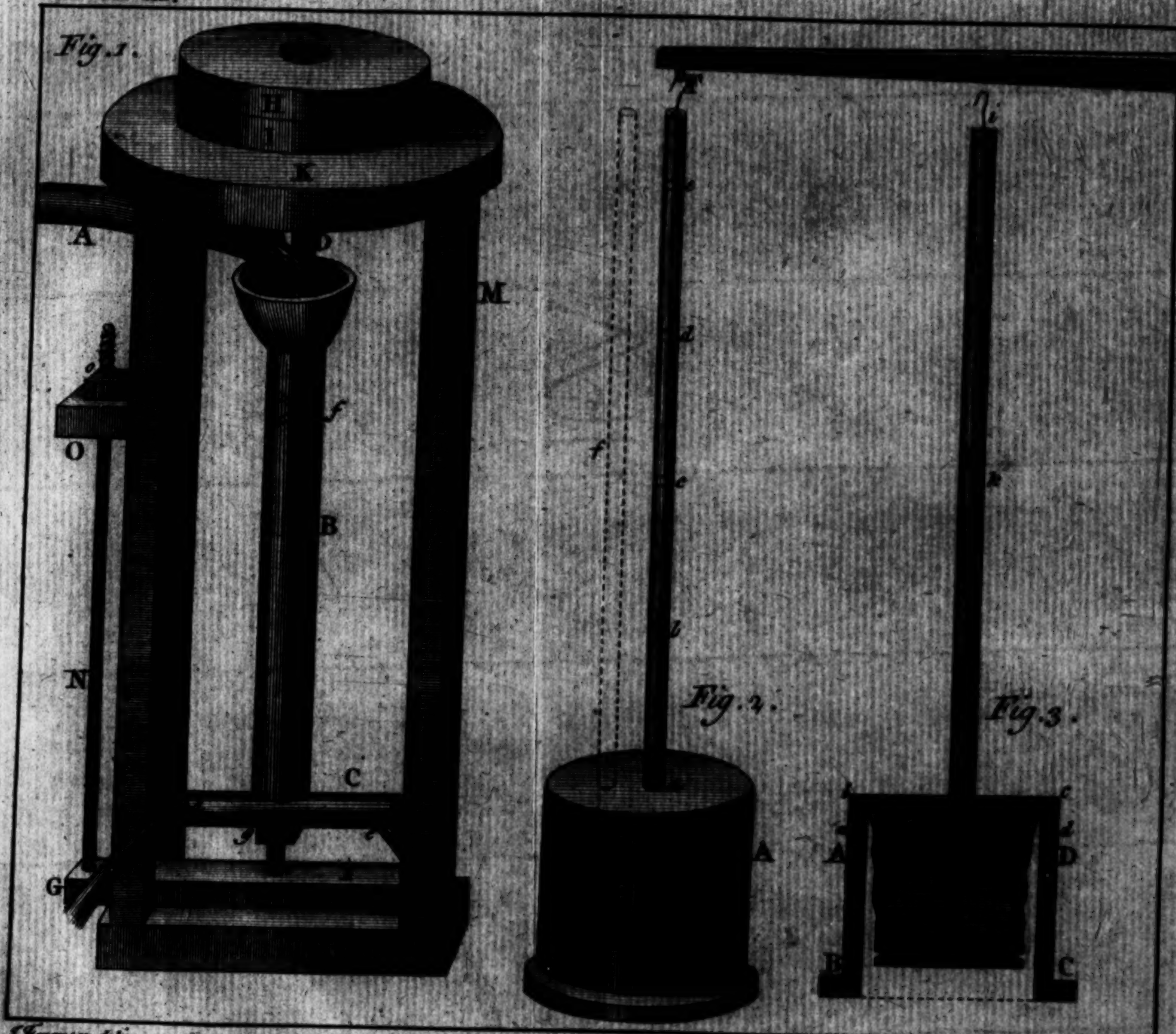
PLATE II.



J. Ferguson delin.

J. Mynde sc.

PLATE III.



J. Ferguson delin. J. Mynde sc.

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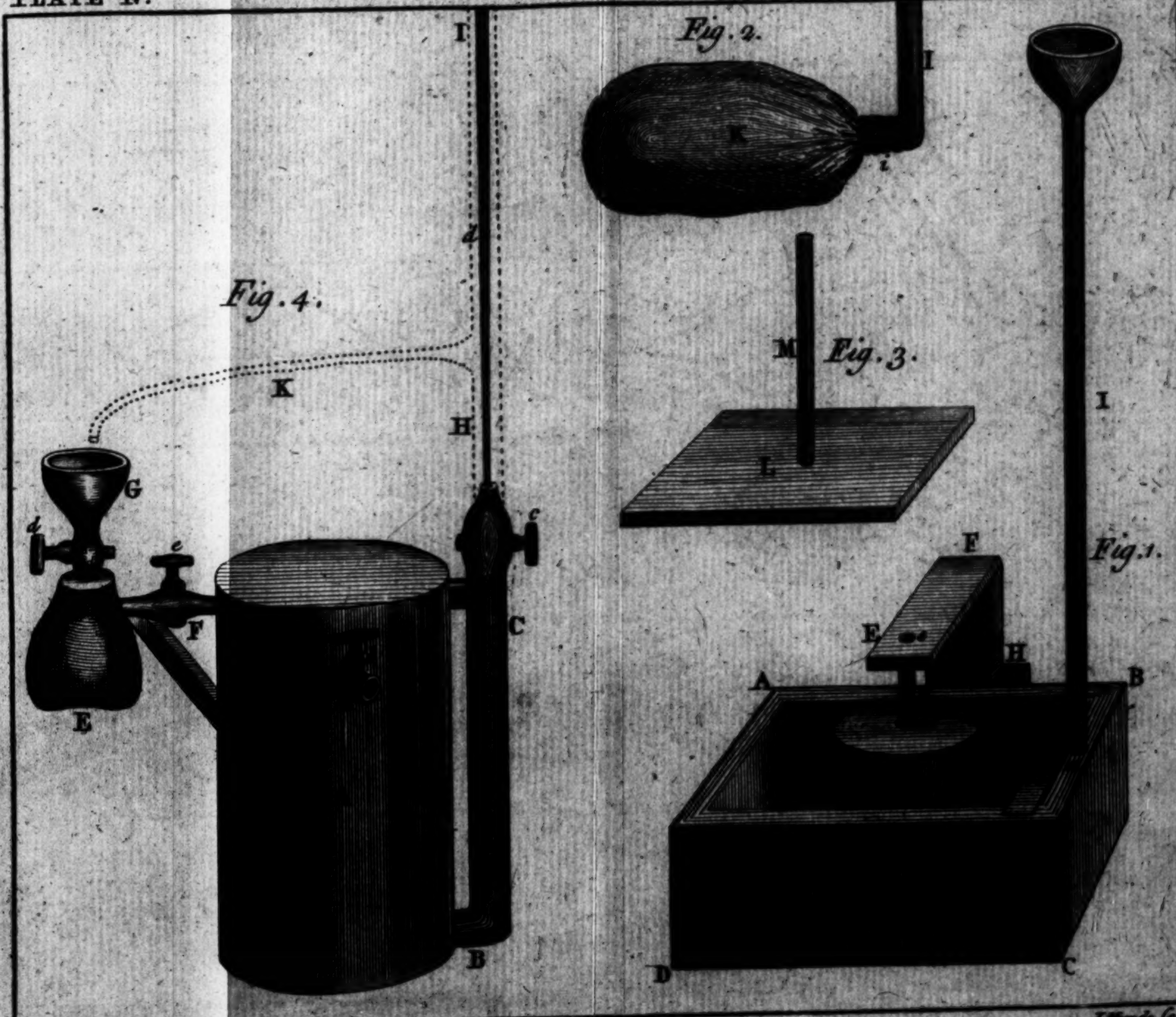

J. Ferguson delin.

J. Lizars sc.

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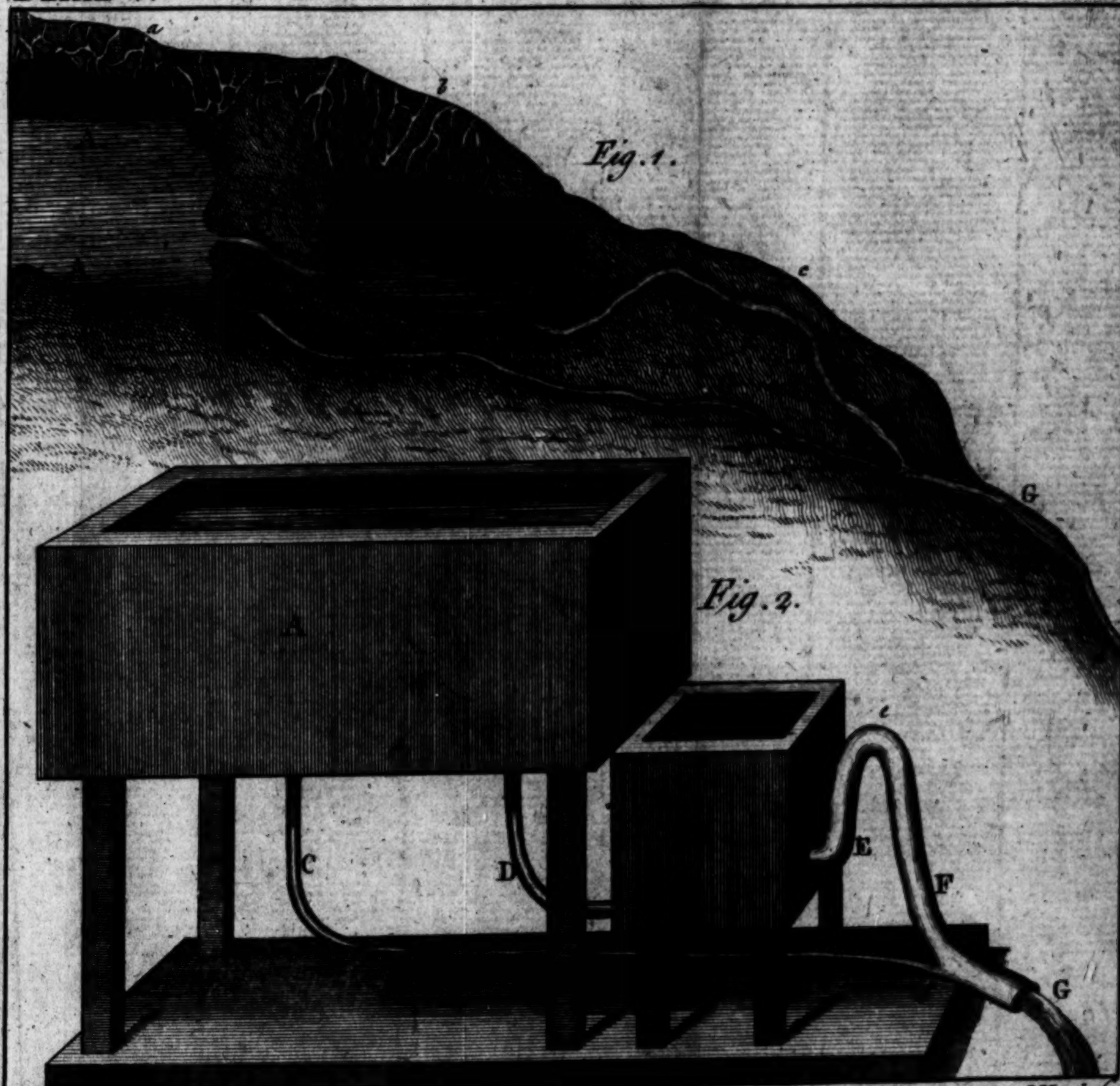


J. Ferguson delin.

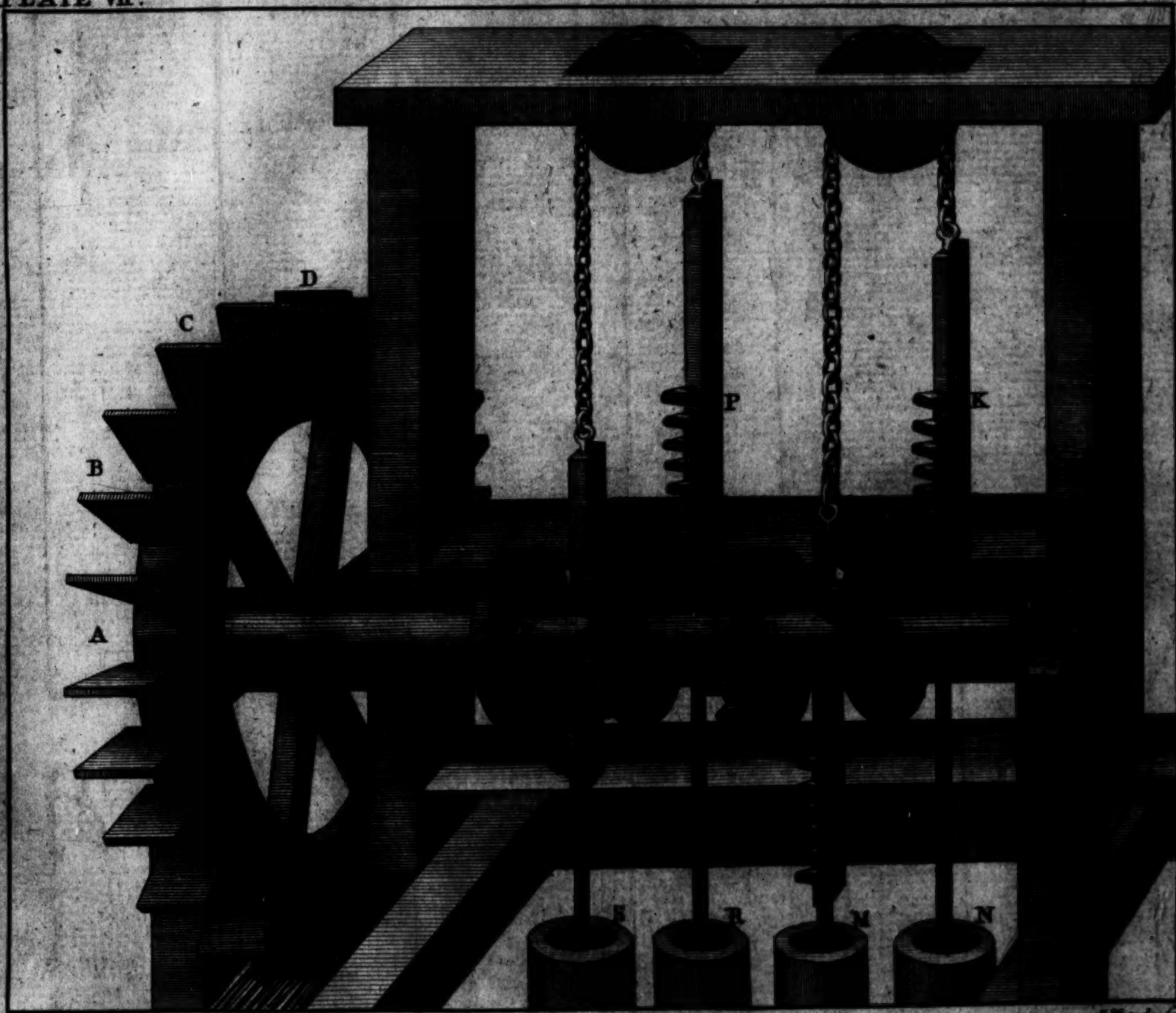
J. Mynde sc.

PLATE VI.

T. Ferguson delin.

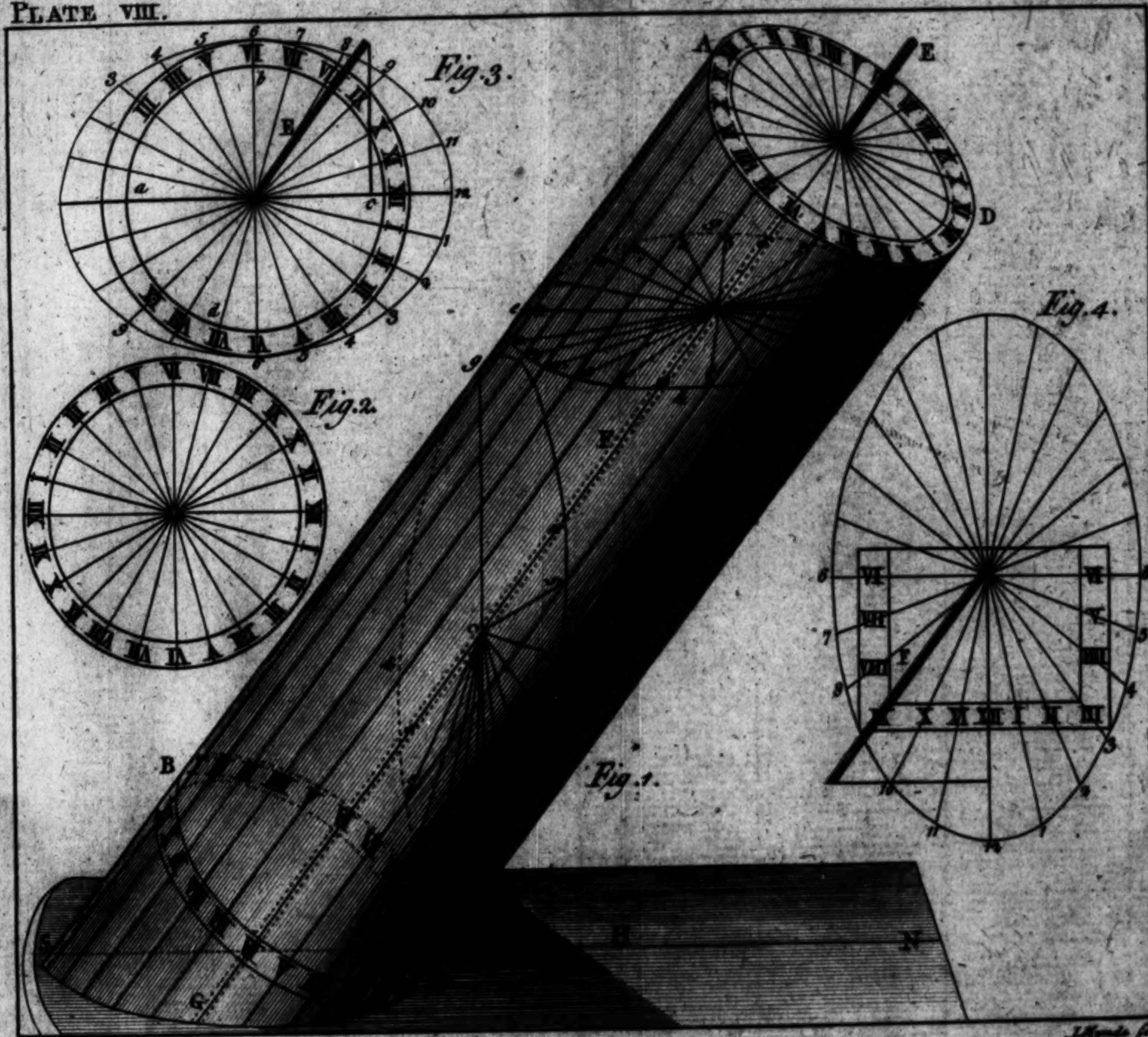
J. Mynde sc.

PLATE VII.



J. Ferguson delin. J. Mynde sc.

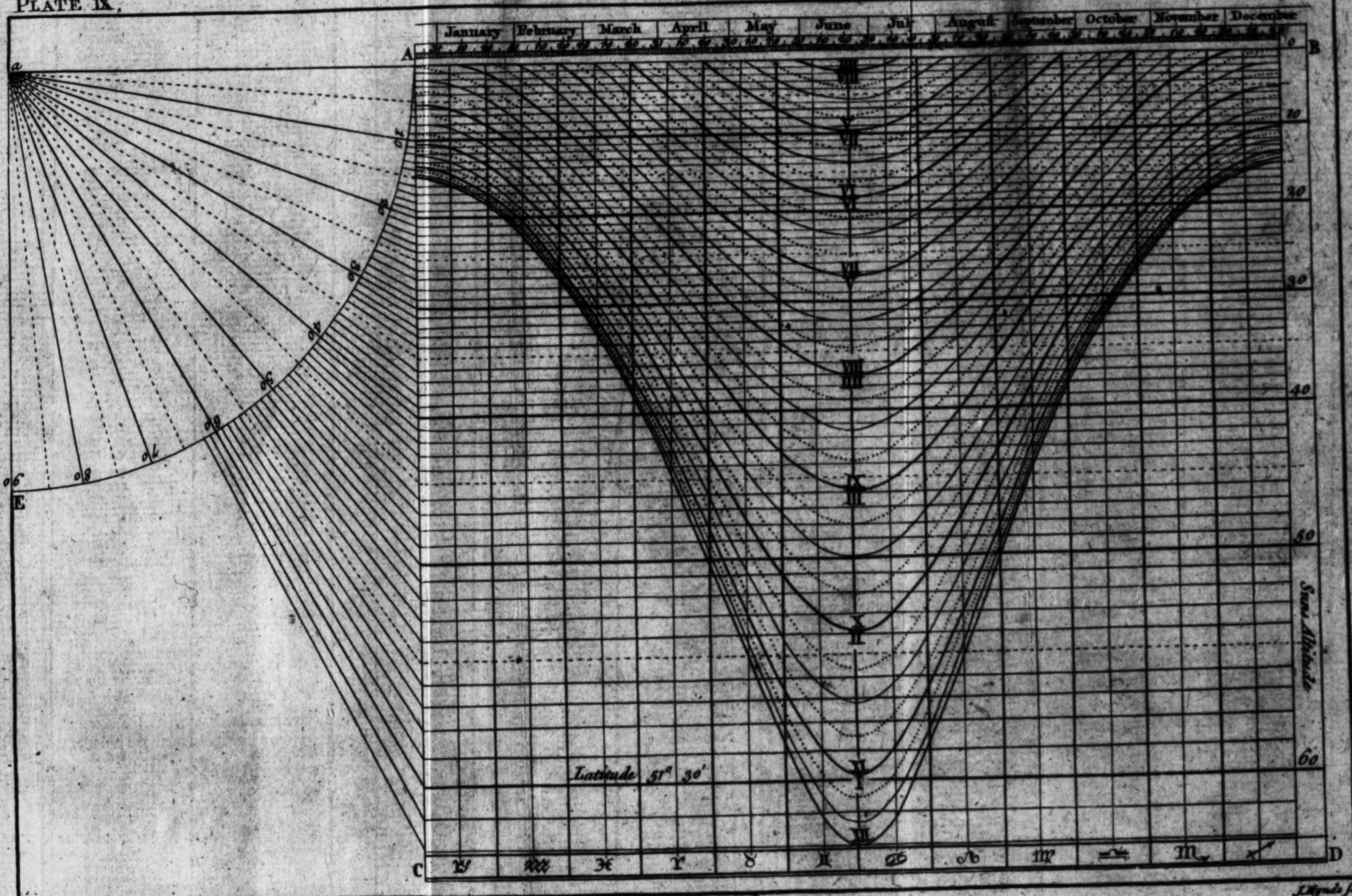
PLATE VIII.



J. Ferguson delin.

J. Mynde sc.

PLATE IX.



J. Ferguson delin.

J. Hynde sc.

PLATE X.

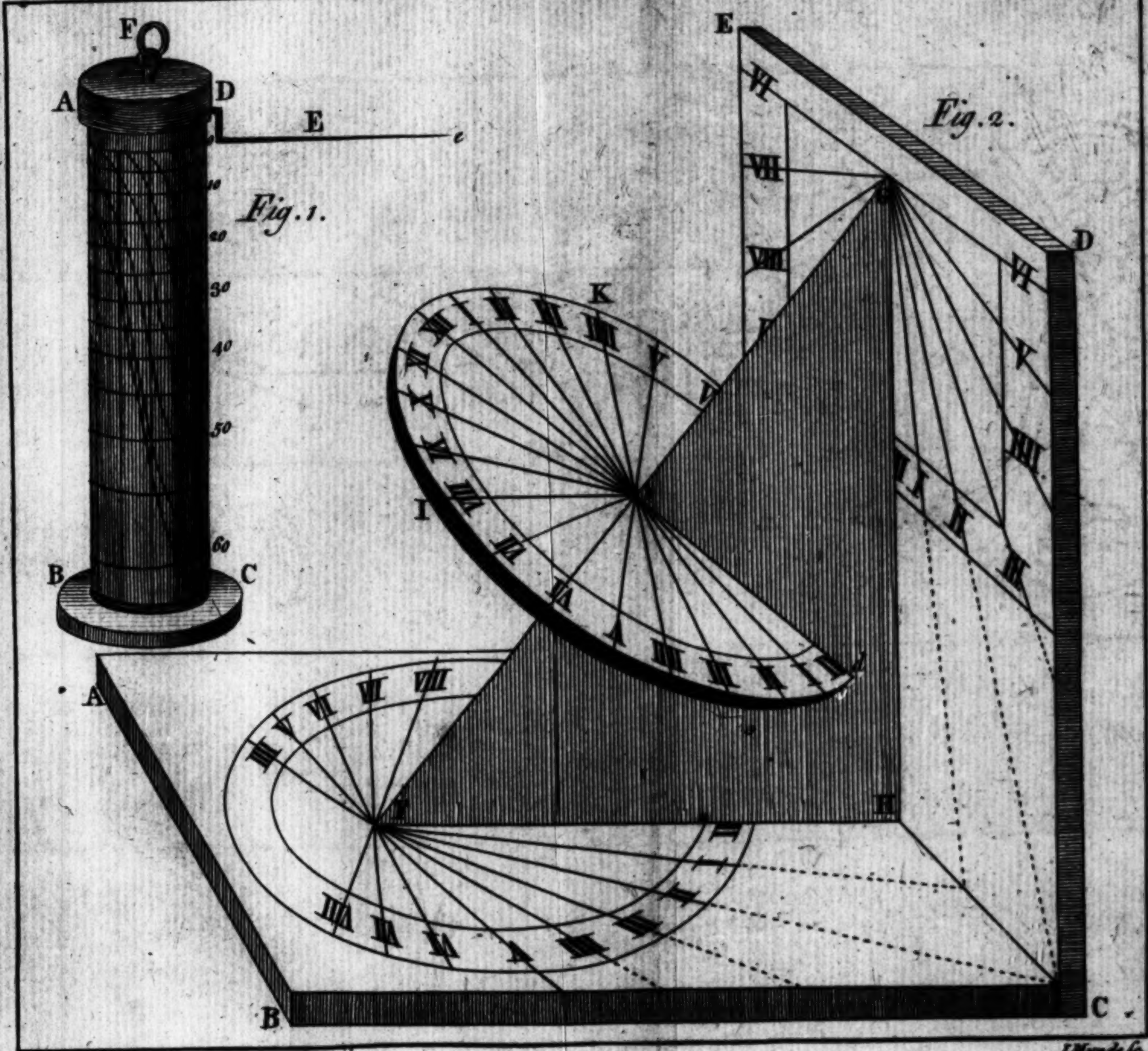


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PLATE XI.

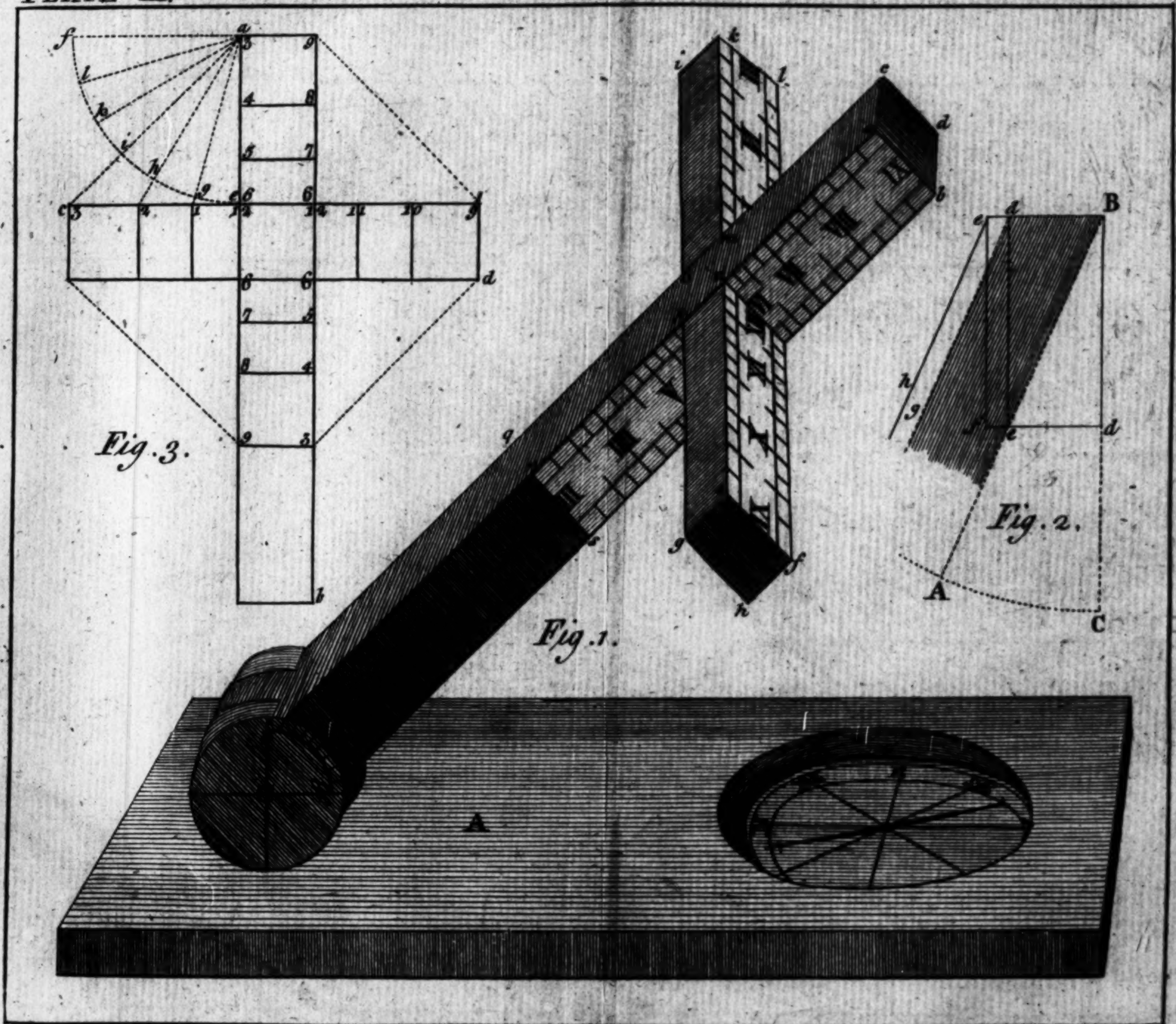

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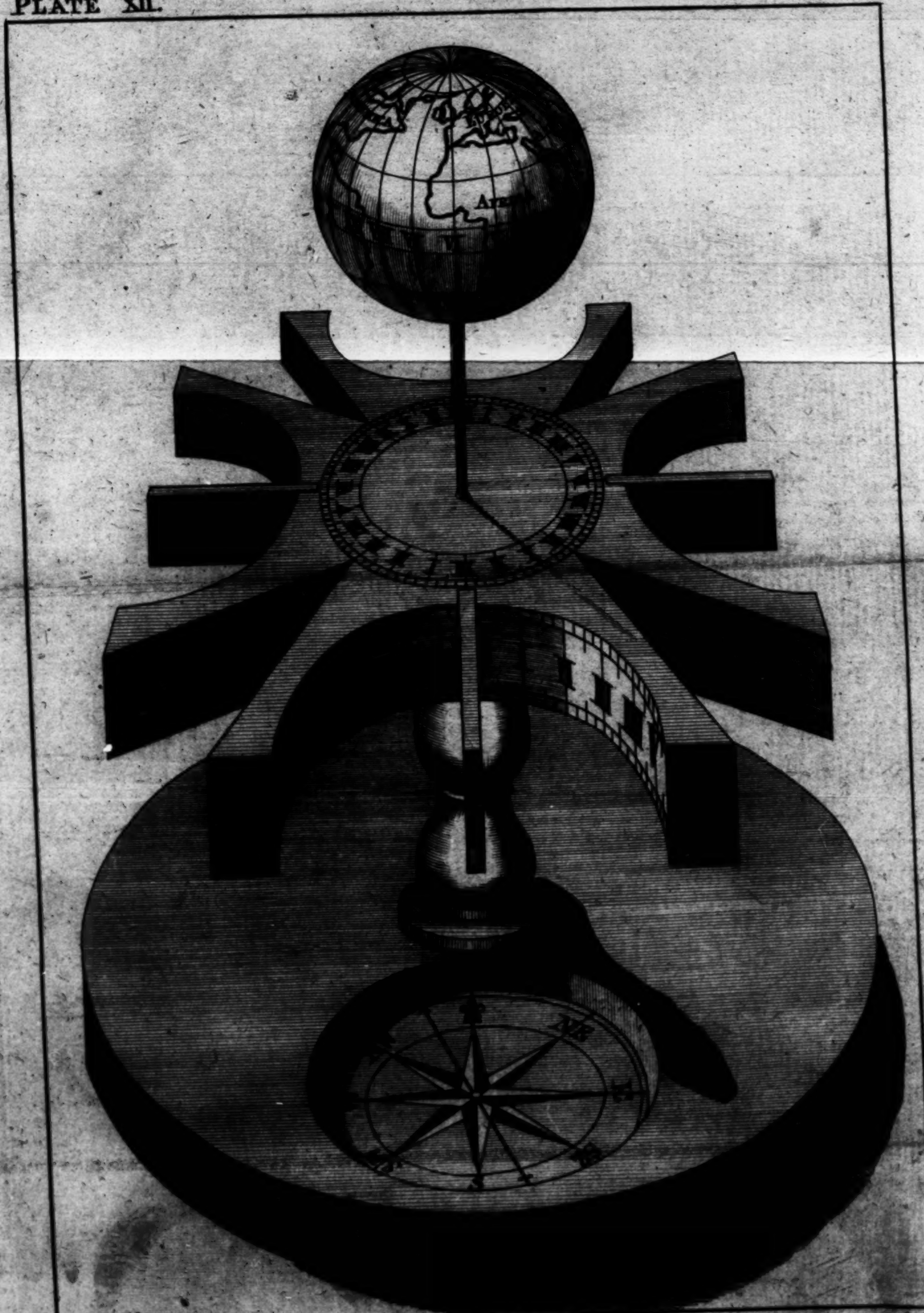
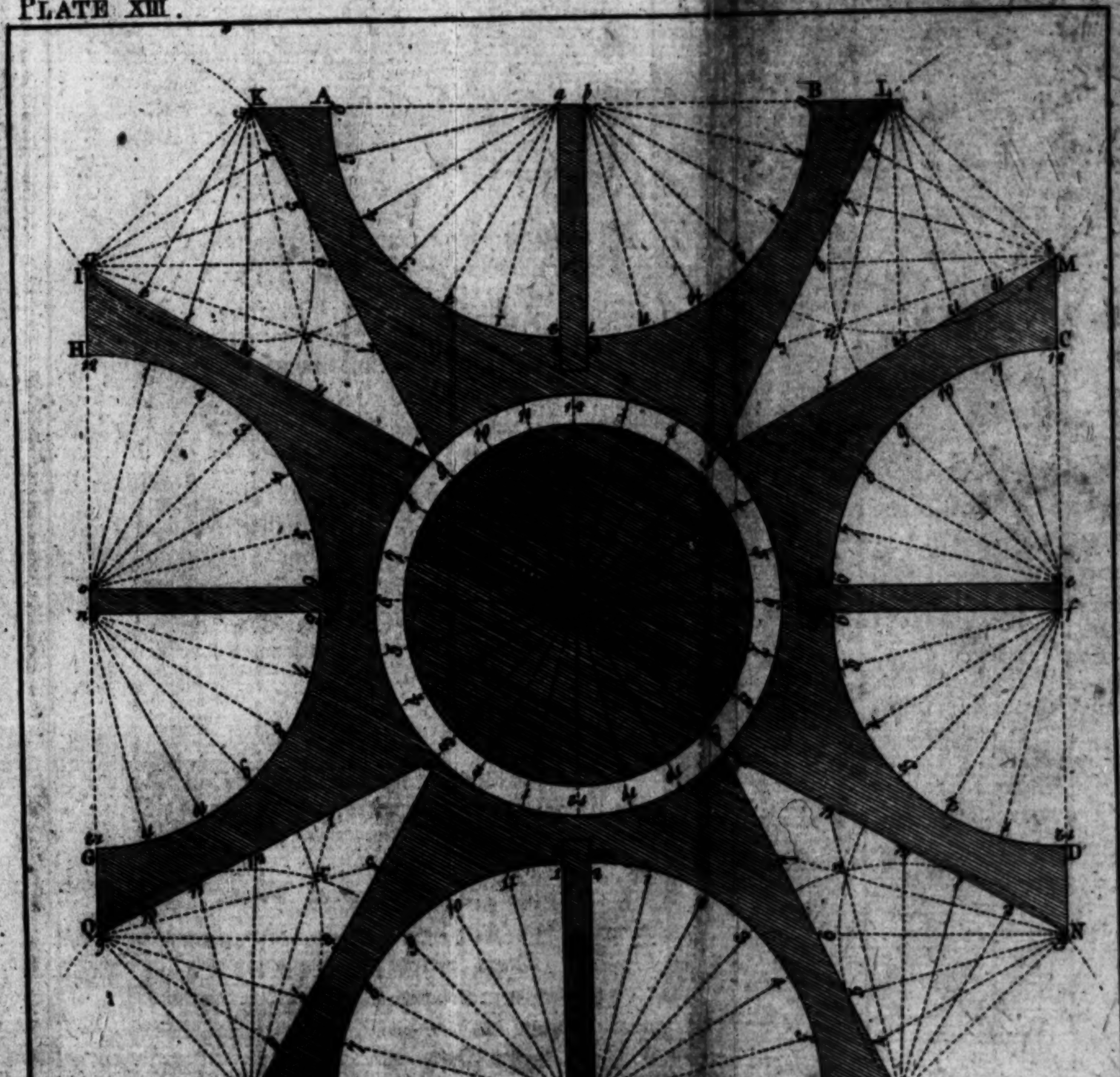
PLATE XII.



J. Ferguson delin.

J. Mynde sc.

PLATE XIII.



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